NOAA Technical Memorandum NOS CS 30

REVISED VDATUM FOR EASTERN FLORIDA

Silver Spring, Maryland
April 2013

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U.S. DEPARTMENT OF COMMERCE
National Ocean Service
Coast Survey Development Laboratory

Office of Coast Survey
National Ocean Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

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REVISED VDATUM FOR EASTERN FLORIDA

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ABSTRACT

VDatum is a datum transformation software tool developed by NOS that provides conversions between tidal, orthometric, and ellipsoidal vertical reference frames. A VDatum application was created for Florida and the South Atlantic Bight, covering the U.S. coast from the north at Sapelo Island, Georgia, and to the south at Fort Lauderdale, Florida. The original application became operational in April 2010. Users at the Jacksonville, Florida, District of the U.S. Army Corps of Engineers found some apparent problems in the datum conversion data when they used VDatum to create gridded fields of the differences between NAVD 88 and MLLW for eastern Florida. Most of the problems were attributed to spurious tidal transformations over barrier islands. To remedy this problem it was decided to split the VDatum region for eastern Florida into two smaller regions, with an inner (western) and outer (eastern) region, each with a new bounding polygon. The border between the two regions would act to separate the inland waterways from the offshore region. Following standard procedures, new data files for the tidal datums and topography of the sea surface were generated for each new region and tested. The new version became operational in April 2012.

1. INTRODUCTION

VDatum is the National Ocean Service's (NOS's) vertical datum transformation software tool that provides spatially-varying conversions between tidal, orthometric, and ellipsoid-based three-dimensional reference frames. The software can convert any ellipsoidally-referenced vertical elevation to the North American Datum of 1983 (NAD 83) by parametric models, NAD 83 to the North American Vertical Datum of 1988 (NAVD 88) by a gridded geoid model, NAVD 88 to the Local Mean Sea Level (LMSL) by a gridded sea surface topography model, and LMSL to any tidal datum with a set of gridded tidal datum transfer fields. Data for the parametric models were obtained from the geodetic literature, and the gridded data were generated by spatial interpolation of known values at numerous locations and by the use of hydrodynamic models.

VDatum files were recently created for a region covering Florida and the South Atlantic Bight (Yang et al., 2012), extending along the U.S. coast from the northeast at approximately Wilmington, North Carolina; southward through South Carolina and Georgia; and ending on the western end in the Florida panhandle at Apalachicola Bay. Five separate sets of grids were required to cover this area (Figure 1a) and the tidal data were populated by output from a hydrodynamic model covering much of the Southeast U.S. (Figure 1b). This original application became operational in April 2010.

(a)   (b)
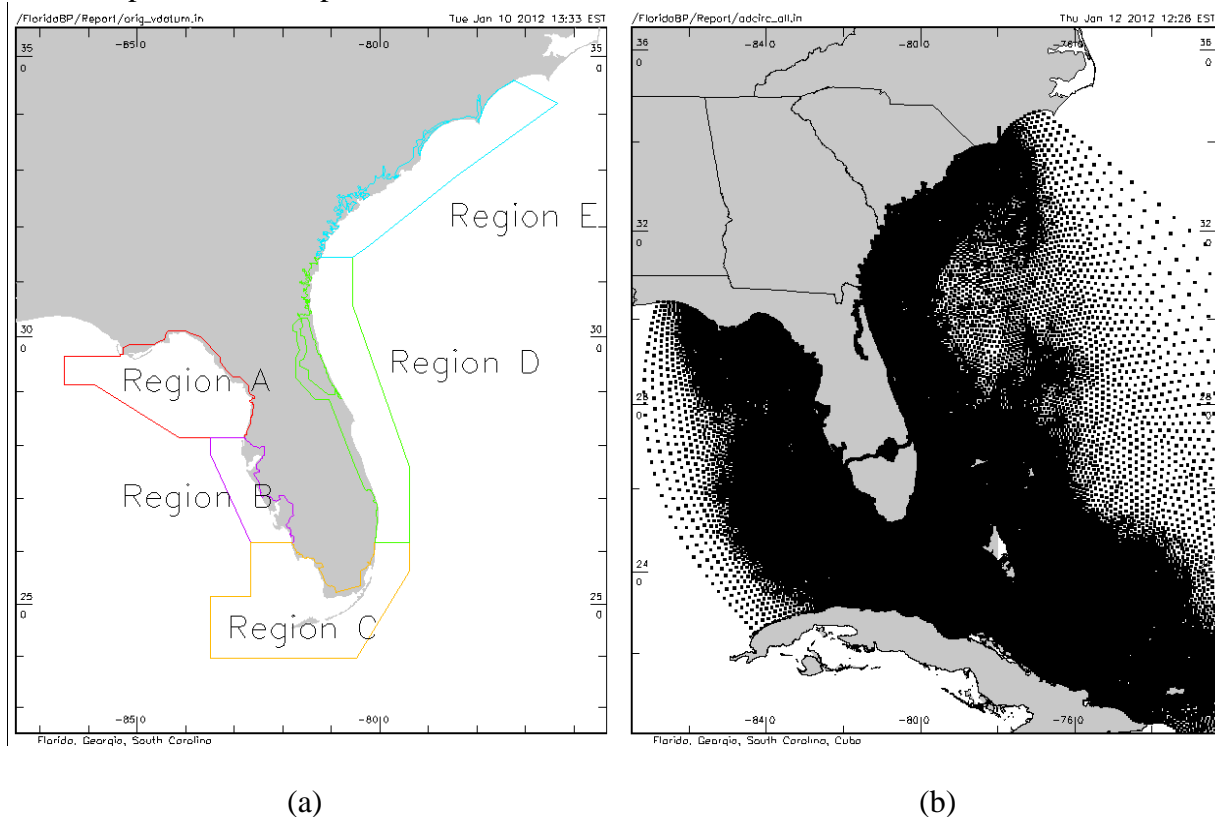
Figure 1. (a) Illustration of the five marine grid bounding polygons for VDatum regions, called A to E. (b) Area covered by the hydrodynamic model (black dots).

Following standard NOS procedures, the VDatum gridded information undergoes extensive testing before being released to the public (NOS, 2011). However, users at the Jacksonville, Florida, District of the U.S. Army Corps of Engineers (USACE) found some apparent problems in the data when they used VDatum to create gridded fields of the value of the difference between NAVD 88 and MLLW (Appendix A). The Coast Survey Development Laboratory (CSDL) of NOS' Office of Coast Survey (OCS), reviewed the problems, and found that most occurred in Region D (see Figure 1), which we will refer to here as eastern Florida.

The typical problem found was that the values at locations lying on the land between the inland waterway and the ocean are unrealistic (Figure 2a). An examination of the NAVD 88 field (Figure 2b) and the MLLW field (Figure 2c) showed that the problem were in the latter field. This is because they were linearly interpolated from the nearest hydrodynamic model values representing, on the landward side, the waterways and, on the seaward side, the coastal ocean. As a result, the values were not truly representative of either body of water. To remedy this problem it was decided to split Region D into two smaller regions, with an inner (western) and outer (eastern) region, each with a new bounding polygon. The border between the two regions would act to separate the inland waterways from the offshore region. This splitting eliminated the problem of erroneous values at overland points. The generation of the new VDatum regions is discussed in Section 2.

Most of the other problems found by the USACE could be traced to the fact that NAVD 88 values were not available at some tide stations at the time the topography of the sea surface (i.e., the difference between NAVD 88 and LMSL) fields were originally generated. This problem could be remedied by the re-generation of the topography of the sea surface fields using the more recent data.

Since the production of the original VDatum applications, a new VDatum requirement was been added: designation of non-tidal areas. In these areas the astronomical tide is small, and as such the difference between Mean Sea Level and any other tidal datum is assumed to be zero. Since there are significant non-tidal areas in Florida, changes in the gridding software were required, which produced some secondary problems of their own.

This report documents recent work by NOS' National Geodetic Survey (NGS), CSDL, and the Center for Operational Oceanographic Products and Services (CO-OPS) to revise and implement the revised VDatum application. This report includes sections on the development of the new marine grids, the revised topography of the sea surface (TSS) field, the testing of the new gridded data, and calculation of the uncertainty values.

The new VDatum regions ('Florida/Georgia- Shelf, Fort Lauderdale FL to Sapelo Island, GA, Version 02' and 'Florida/Georgia- Coastal waterways, Fort Lauderdale FL to Sapelo Island, GA, Version 01') became operational on the VDatum website in April 2012.

(a)

(b)

(c)
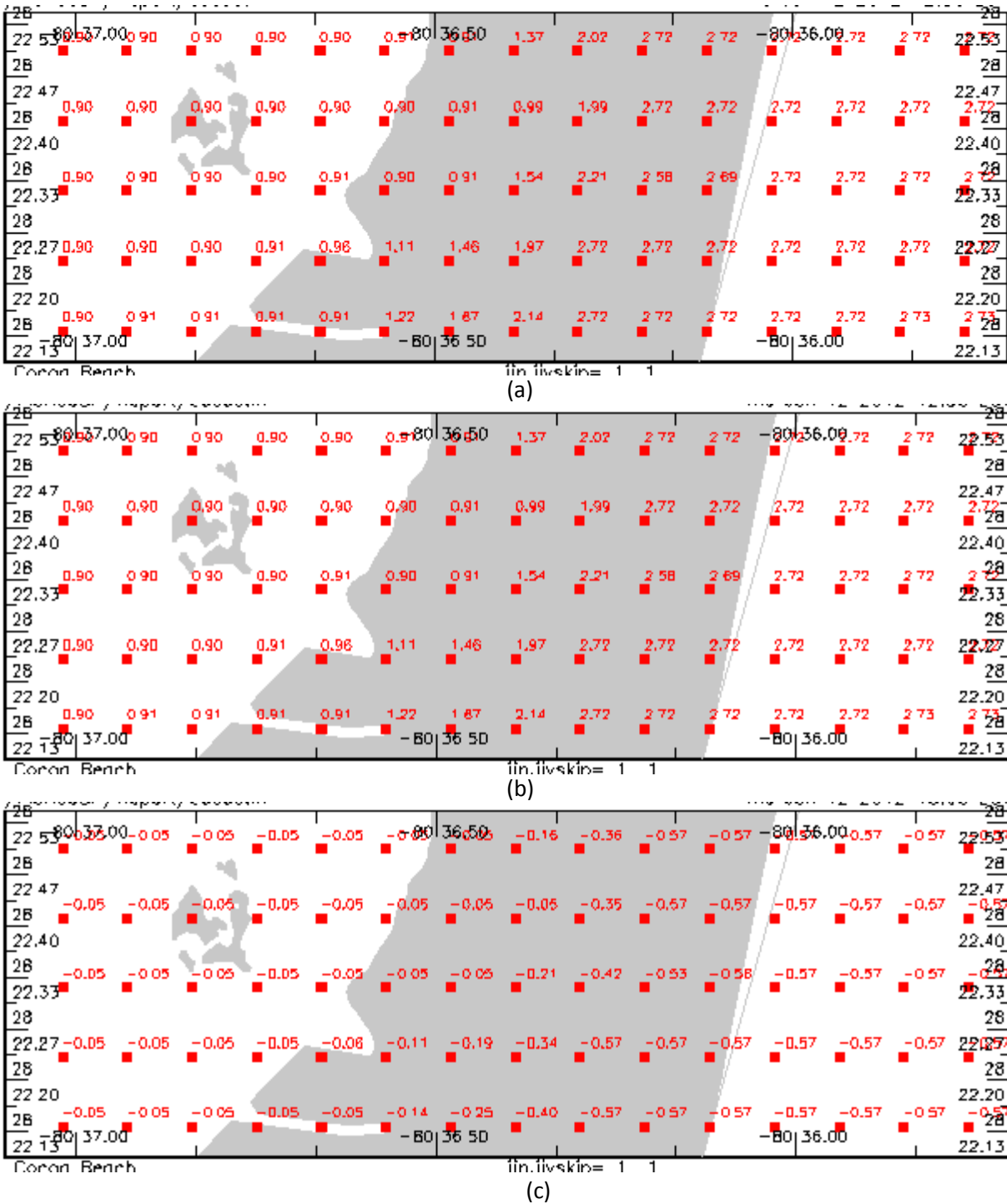
Figure 2. Gridded VDatum values in the vicinity of Cocoa Beach, Florida. The ocean is at the right and the inland waterway (Banana River) is on the left. Gray areas denote land. Plots show the grid points and the values of the difference between (a) NAVD 88 and MLLW, with problematic values on the land; (b) NAVD 88 and MSL, with no problematic values on the land; and (c) MSL and MLLW, with problematic values on the land (i.e., increasing from right to left), which are the source of many of the problems found by the U.S. Army Corps of Engineers.

2. DEVELOPMENT OF THE REVISED VDATUM FILES

As was discussed above, it was decided to split the original Region D into two smaller regions, with an inner (western) and outer (eastern) region, each with a new bounding polygon. The border between the two regions would act to separate the inland waterways from the offshore region. Development of the new VDatum files follows a sequence: creation of the bounding polygons, generation of the marine grids, and population of the marine grids. A marine grid is a structured array of points that designate either land or water. The grids have a constant vertical and horizontal spacing. These steps are discussed below. A fourth step is the testing the new VDatum files; this is discussed in Section 4.

VDatum has evolved since the original Florida application. A new feature is the use of non-tidal areas. CO-OPS designates certain areas as being non-tidal, i.e., there is no significant tidal variation. In practice, this usually means that the mean tide range is less than 0.03 m (M. Michalski, personal communication). In addition, in these regions, another tidal datum is often used: the LWD. For hydrographic surveys, LWD is usually taken as 0.154 m (0.5 ft) below MSL. There are three such areas within Region D: Lake Okeechobee, Lake George, and the waters inland of Cape Canaveral (see Figure 3a). The non-tidal areas are now taken into account when generating the tidal datum fields.

2.1 New Bounding Polygons

The first step in dividing the original Region D into two new regions was the creation of new bounding polygons (BPs). A BP functions to determine which set of VDatum grids will be used for tidal transformations at a given latitude-longitude location. The BP is necessary since VDatum grids usually overlap those of adjacent regions, and it may not be obvious by visual inspection which one is applicable. Overlapping grids are usually required where there are adjacent coastal waters with different tidal ranges, separated only by narrow barrier islands.

It was decided to separate the entire region along a line running from the northern boundary at Sapelo Island, Georgia, to the southern end just north of Fort Lauderdale, Florida. The dividing line between the two regions was generated by numerically estimating the position of the middle of the barrier island every few kilometers up the coast, then refining the position to account for inlets and other coastal features. A more detailed discussion appears in Appendix B. Adjustments were made in the dividing line to ensure that the non-tidal polygon was everywhere on the landward side. The dividing line was then used, along with the borders of the original BP, to create the two new BPs (Figure 3). Once the two BPs were available, the new marine grids could be constructed (Section 2.3).
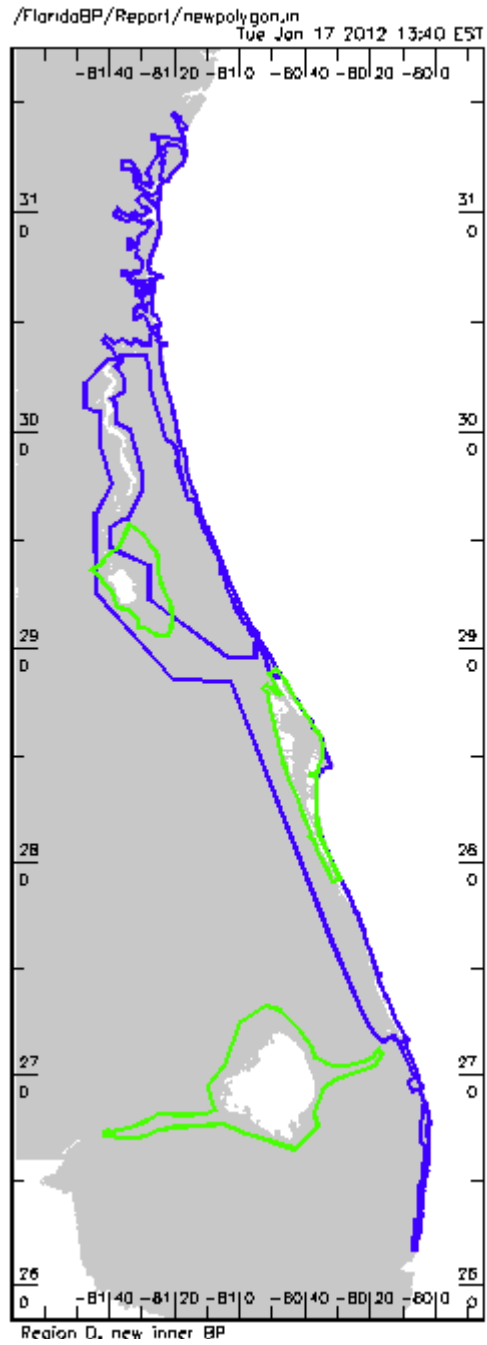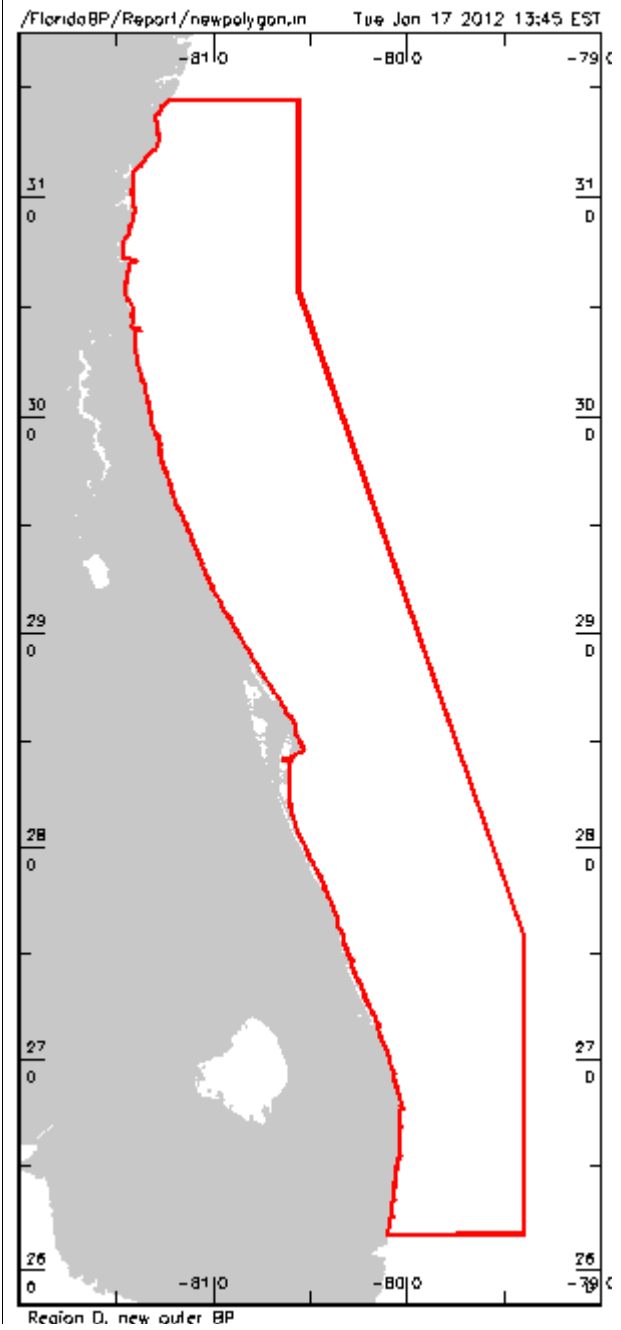
Figure 3. Eastern Florida land (gray) and bounding polygons for (a) the inner region (BP in blue) and (b) the outer region (BP in red.). The non-tidal areas are denoted by the green polygons.

2.2 Non-tidal Polygons

Since the production of the original Florida VDatum grids (Yang et al., 2012), there is now a new capability to designate specific geographic areas as non-tidal. These areas are defined by CO-OPS as having no significant tidal variation, i.e., having a mean tide range of 0.03 m or less. Non-tidal regions are delineated by polygons (Figure 3), and two of these lie within the new, inner BP: a more northerly one located around Lake George on the St. Johns River, and another encompassing much of the inland waters (the Indian and Banana Rivers) around Cape Canaveral. The third surrounds Lake Okeechobee and its approaches, and lies outside both the inner and outer BPs.

Within these non-tidal regions, the MSL is defined as the Mean Water Level (MWL), and all tidal datum transformation values are taken to be zero. Also, LWD, a new vertical datum, is available and is defined as 0.5 ft (0.1524 m) below MLW. This datum has been used historically in the Pamlico Sound region of North Carolina by NOS for its hydrographic surveys.

2.3 Marine Grids

To replace the single grid for the entire are of Region D (Figure 1a), two new marine grids were developed. It was decided to use the same spacing as was used in the original Region D: $dx = dy = 0.0015$ degrees. Note that for this spacing, dy is 0.090 nautical miles or 166 m, and at the latitude of Cape Canaveral, dx is 0.079 nautical miles or 146 m. The parameters of the new grids are shown in Table 1.

Table 1. Marine grid parameters. X0 and Y0 are the geographic coordinates (deg) lower left corner of the grid, DX and DY are the horizontal and vertical spacing (deg), and IMAX and JMAX are the number of points in the horizontal and vertical directions.

Region	X0	Y0	DX	DY	IMAX	JMAX
Inner (Coastal Waterways)	-81.795	26.166	0.0015	0.0015	1185	3526
Outer (Shelf)	-81.471	26.166	0.0015	0.0015	1386	3523

The points within each grid, and within the respective BP, are determined to denote either land or water, depending on whether they are inside an island or other land mass, or not. An automated procedure (`vgridder15.f`) and a digital coastline file were used to make the determinations.

In addition, at the request of NGS, the points designating water were extended so as to cover some of the inland areas. In this iterative procedure for each layer, land points are turned into water points if one or more points that are adjacent in the horizontal or vertical direction are (a) water and (b) were water at the start of the iteration. Using this procedure, three layers were added. After the initial marine grids were generated, a few modifications to the grid were then made after a review by the staff of NGS. The marine grids are shown in Figure 4. However, the addition of layers led to a complication when used in conjunction with non-tidal areas. This problem and its solution are discussed in Section 2.4.
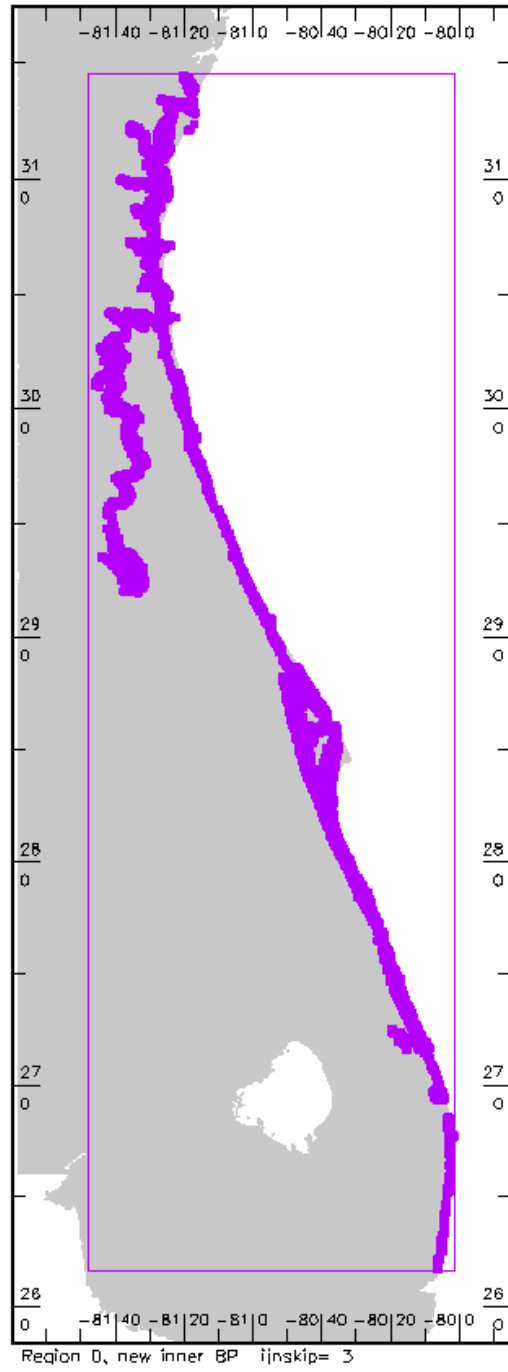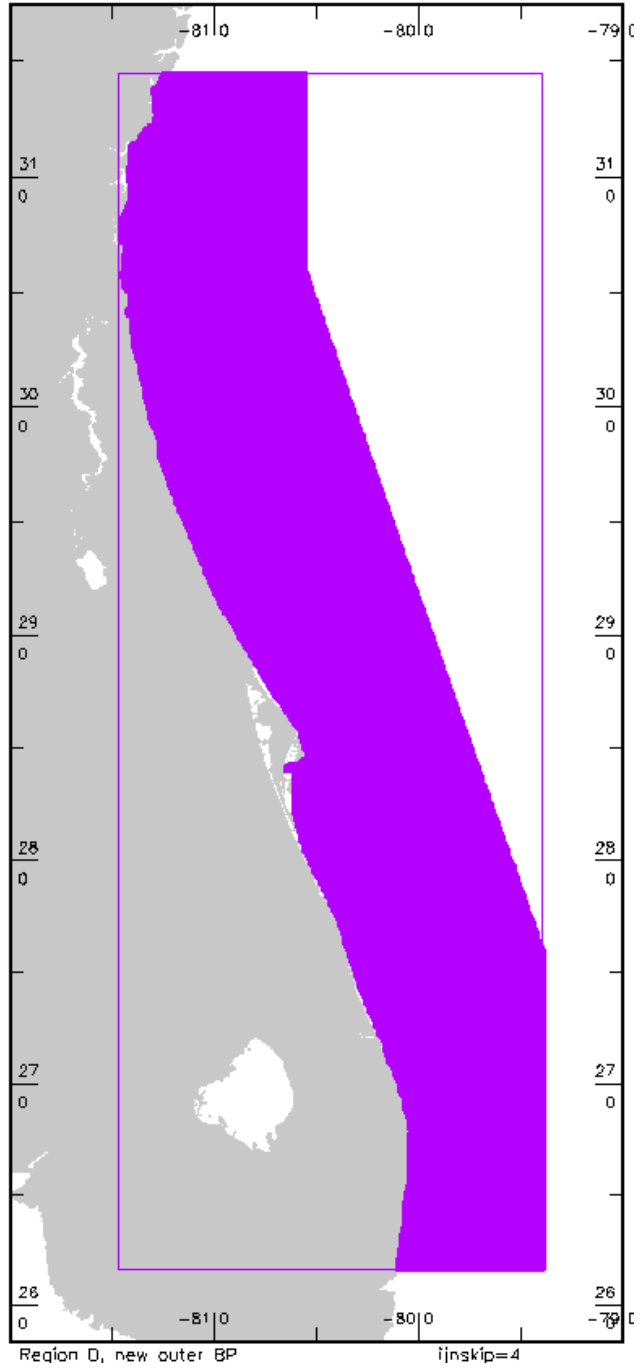
Figure 4. Active (i.e., non-null) points (purple) in the marine grids for the revised eastern Florida (a) inner region and (b) the outer region.

2.4 Population of the Marine Grids

The marine grids were populated with the output of the ADvanced CIRCulation (ADCIRC) hydrodynamic model for the region (Figure 1b). The data from the original model runs (Yang et al., 2012) were used in this project; no additional tidal model runs were carried out. However, the tidal datum fields produced by the model were newly adjusted to fit the latest observed values at the tide stations using spatial interpolation of the error field, which was added to the hydrodynamic model results.

The new error field was computed using a PYTHON program which spatially-interpolated the error at the tide stations using the TCARI algorithm (Hess, 2002) on an unstructured grid. The new tidal datums at tide stations were taken from the file `merged_20111107.dat`. This file contains the datum values for Florida that appeared on the tidal datums website of CO-OPS on November 7, 2011, and copied by CSDL. The tide stations and their values are listed in Appendix D.

The marine grids were filled in a four-phase process as explained below.

Phase 1, Model Fill - In the first phase, the ADCIRC-generated datum fields were used to populate the grids. The method of population (using program `vpop23.f`) consists of three basic steps. First, all water points that lie within an ADCIRC element are filled with a value determined by linear interpolation of the values at the element's nodes. Next, to account for narrow channels, unfilled water points are filled by a distance-weighted mean of the ADCIRC values that lie within half a grid distance. Finally, unfilled points that lie outside any element are filled by a weighted sum of the adjacent filled values. [This step is essentially unchanged from previous versions of the population program]

Phase 2, Tidal Order - This phase involved checking for tidal order (see Section 4). The correct tidal order means that at every water point the MHHW value is greater than the MHW value, the MHW value is greater than the MLW value, and the MLW value is greater than the MLLW value. Occasionally, the datums at some points may not meet this criterion due to aberrations in the filling scheme; they can now be corrected in `vpop23.f` at the time the fields are generated. Given a small positive value, ε, the positive datums (MHHW and MHW) are reset to ε if they are less than zero, and the negative datums (MLW and MLLW) are reset to $-\varepsilon$ if they are greater than zero. Then the tidal order is checked. For example, if at a point MHHW < MHW, then both are reset as follows.

$$MHHW_{new} = \frac{1}{2}(MHHW + MHW) + \varepsilon$$

$$MHW_{new} = \frac{1}{2}(MHHW + MHW) - \varepsilon$$

The other tidal datums are then checked for order. Usually several iterations are required before all the datums are in the correct order. Here we used $\varepsilon = 10^{-3}$ m. [This capability resolved some problems seen in gridded fields elsewhere, although not in Florida]

Phase 3, Non-Tidal - Here the non-tidal areas are introduced. These areas are designated by CO-OPS as being non-tidal, i.e., there is no significant tidal variation. There are two such regions in Florida in the new inner BP: one near Cape Canaveral and one near Lake George, at the southern end of St John's River, about 60 nautical miles northwest of the cape. To remedy one of the problem areas found by the USACE, the polygon for the Cape Canaveral area was modified, primarily to include more water area in Port Canaveral (see Appendix C).

Here, values for water points within the non-tidal polygons are modified. A user-supplied alternate value for the tidal datum is substituted, and a new datum file is created which has another user-supplied reference value at all points within the non-tidal polygons. At this writing, the user-supplied alternate value is 0.0 m and the user-supplied reference value is -0.1524 m (or -0.5 ft). The reference value corresponds to the LWD occasionally used by OCS as the chart datum for non-tidal areas. [This step represents the new capability required to incorporate non-tidal areas]

Phase 4, Layers - In this phase, the points in the additional layers are filled. However, the addition of layers led to a complication when used in conjunction with non-tidal areas. Initially, tidal values were extrapolated to the additional layers before checking for non-tidal areas (Phase 3). This could lead to the possibility that a point on the land can have a significant tidal datum value, but be adjacent to a water point with a datum value that was zero. This could happen when the additional layers extended further landward than did the non-tidal polygon. The problem was solved by changing the order of filling. First the non-layer water cells are filled in the normal way, then datums in the non-tidal areas are set to zero, and lastly the layer water cells are filled by extrapolation. [This step is also new, and is required to produce correct values at grid points not in water but adjacent to water, even if the water is non-tidal]

After the above four phases are completed, the Mean Tide Level (MTL) and Diurnal Tide Level (DTL) are created by averaging the MHW and MLW and the MHHW and MLLW values, respectively. This new approach, along with splitting the original VDatum region into two, has eliminated most of the problems found by the USACE. The results for Cocoa Beach are shown in Figure 5.

Figure 5. Gridded values in the vicinity of Cocoa Beach, Florida. The ocean is at the right, and the inland waterway (Banana River) is on the left, and the land is gray. Gridded values of the difference (m) between MSL and MLLW for the outer region (red) and inner region (blue) are shown, along with the bounding polygon (purple line) and the non-tidal polygon (green). Compare with Figure 2c.

3. TOPOGRAPHY OF THE SEA SURFACE

The Topography of the Sea Surface (TSS) is defined as the elevation of the North American Vertical Datum of 1988 (NAVD88) relative to local mean sea level (LMSL). This grid provides compensation for the local variations between a mean sea level surface and the NAVD88 geopotential surface over the Florida/Georgia VDatum regions. A positive value specifies that the NAVD88 reference value is further from the center of the Earth than the local mean sea level surface. All data are based on the most recent National Tidal Datum Epoch (1983-2001). The locations of tide stations used are illustrated in Figure 6.

The direct method of obtaining NAVD 88-to-LMSL values includes calculating orthometric-to-tidal datum relationships at NOAA tide gauges where elevation information has been compiled. Data for the direct method were supplied by CO-OPS and NGS.

Next, a continuous surface for each VDatum region was generated representing inverse sea-surface topography (Figures 7 and 8). A mesh covering the entire area of benchmarks and water level stations with a spatial resolution similar to that of the tidal marine grids was created. Breaklines were inserted to represent the influence of land. A sea surface topography field was generated using the Surfer© software's minimum curvature algorithm to create a surface that honors the data as closely as possible. The maximum allowed departure value used was 10^{-4} m. To control the amount of bowing on the interior and at the edges of the grid, an internal and boundary tension value of 0.3 was used. Once the gridded topography field was generated, null values were obtained from the marine tidal grids and inserted to denote the presence of land.

It should be noted that the TSS field covering the South Carolina-North Carolina VDatum (Region E, Figure 1) was also regenerated. This field is shown in Figure 9.

The data used to compile TSS grids was compared against the TSS grid product, to fulfill internal consistency. The differences between NAVD88 and MSL elevations for each tide station utilized for the creation of the TSS are depicted in Appendix E (Table E.1). The mean and standard deviations for these difference values between NAVD88 to MSL relationships are listed in Appendix E (Table E.2).
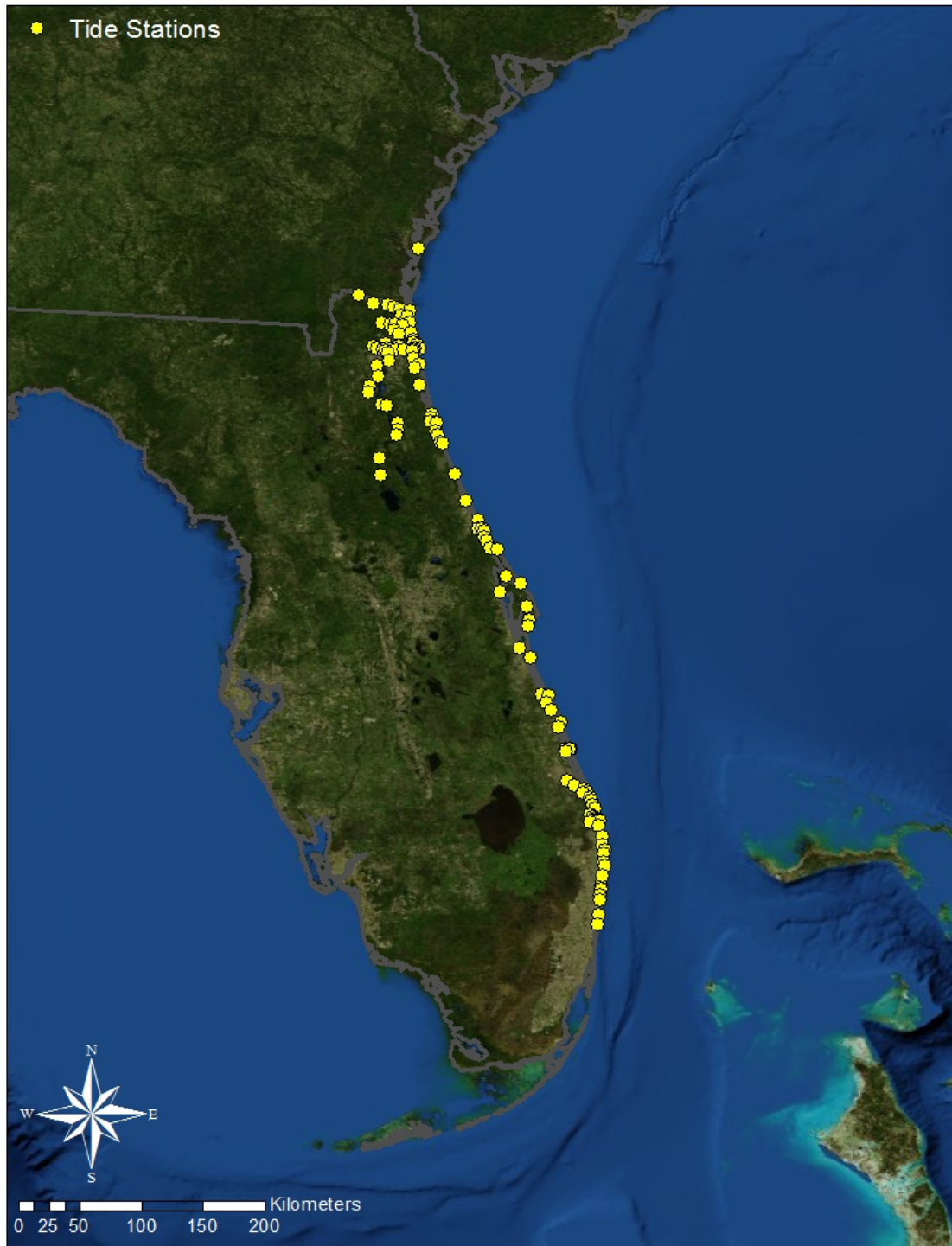
Figure 6. Locations of tide stations used for computing the TSS fields.

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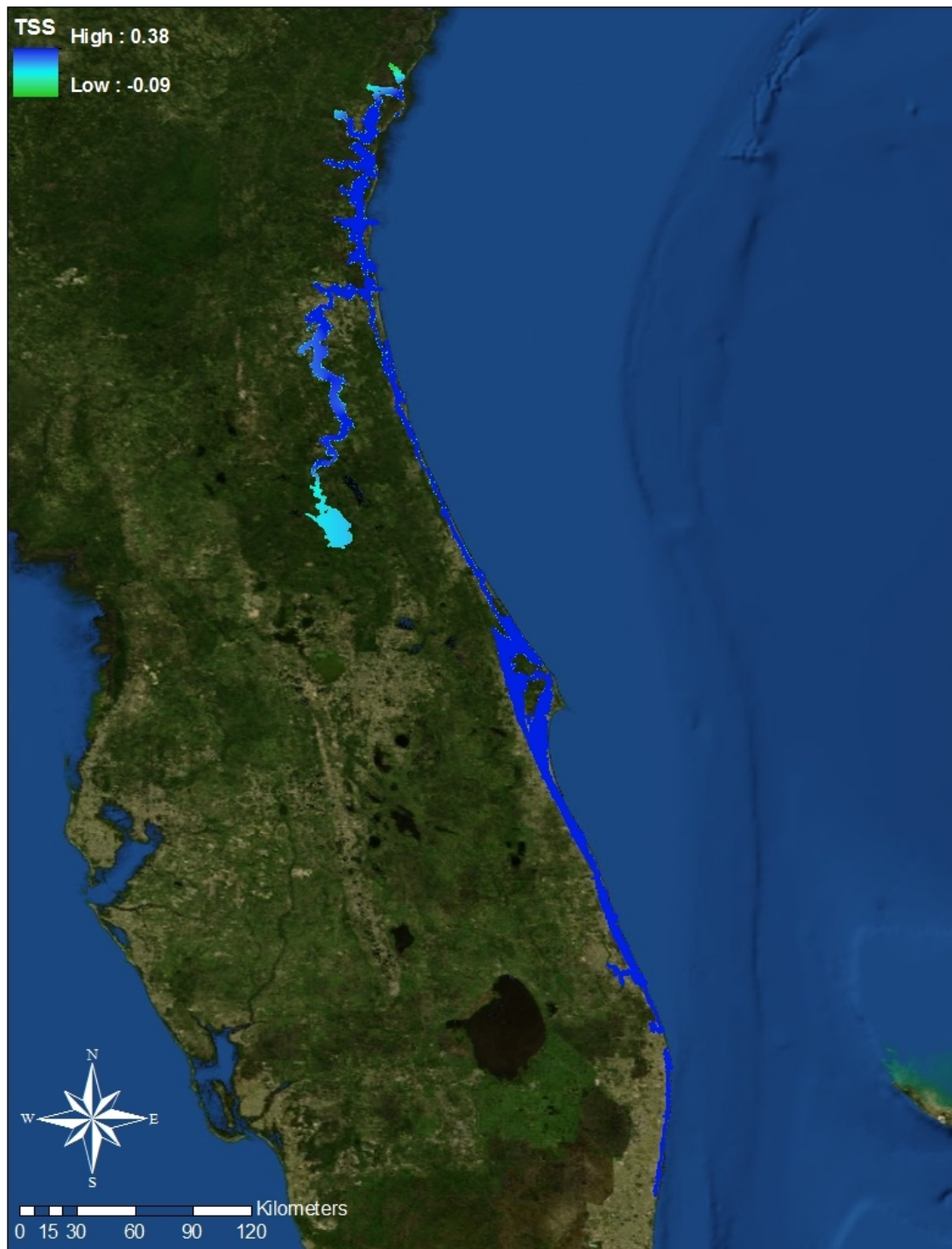
Figure 7. TSS field for the inner region.
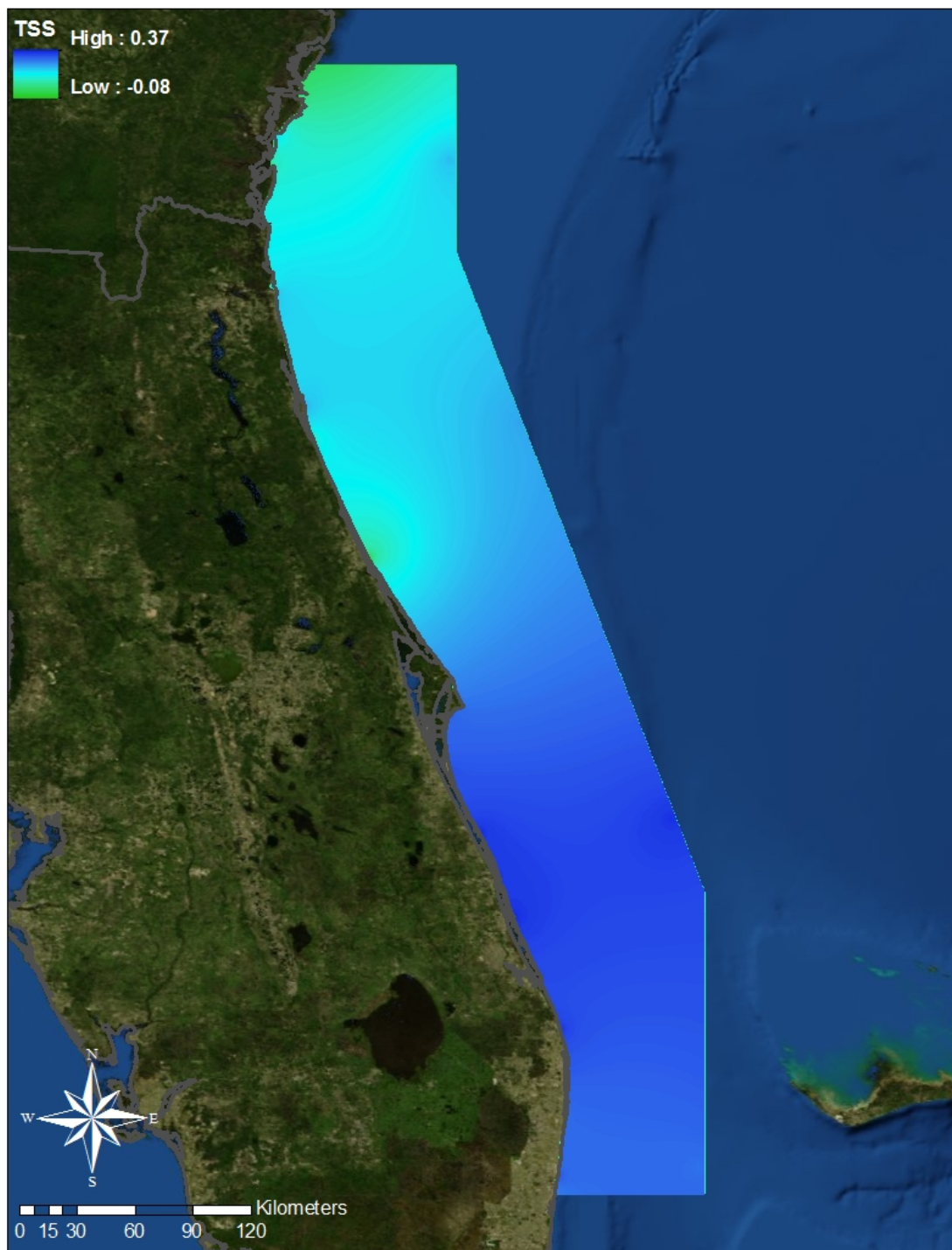
Figure 8. TSS field for the outer region.
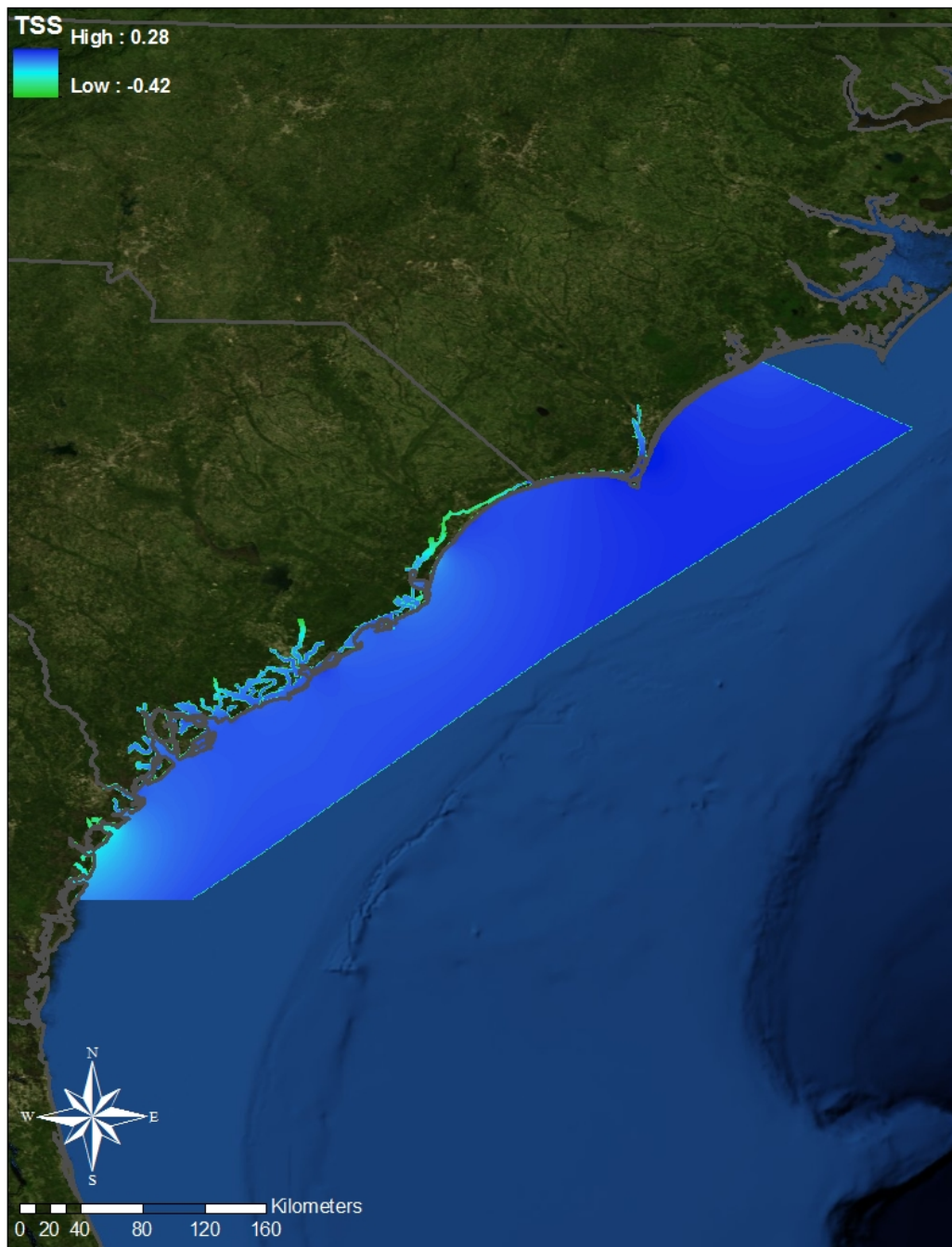
Figure 9. TSS field for the Georgia, South Carolina and North Carolina VDatum region.

4. TESTING

All VDatum marine grid files are tested. The filled marine grids are referred to as the GTX grids. The approach is to use a sequence of tests, performed in order, that inspect the data for validity. The files must pass each step in the testing sequence before going on to the succeeding test.

Polygon Coverage Test - The first test is for compatibility of the area within the GTX grid and the bounding polygon. That is, program `test_poly4.f` inspects each GTX grid to ensure that it completely covers the area within the bounding polygon. That is, the southernmost row must have a latitude that is below the southernmost point in the bounding polygon, the northernmost row must have a latitude that is above the northernmost point in the bounding polygon, and so on. Otherwise an input location may request a grid mesh that does not contain any datum transfer data. If the files do not pass this test, either the bounding polygon or the GTX mesh, or both, must be corrected before any subsequent tests can be performed.

Both polygons are completely inside their GTX files.

Polygon Overlap Test - The second test is for potential overlap of bounding polygons using the program `test_ovlp5.f`. This program checks each vertex in a bounding polygon to see whether it falls within another bounding polygon. Note that vertices are allowed to lie upon the side of another polygon, or to coincide with another vertex. There should be no overlap between polygons, but they may share sides.

The new polygons do not overlap, nor do they overlap with either of the adjacent polygons for Region E and Region C.

Tidal Order Test – In this test, values of the tidal datums at each non-null point in the GTX file are examined by program `test_order7.f` to determine whether the magnitudes are in the logical order; i.e., whether the MHHW value is greater than the MHW value, the MHW value is greater than the MLW value, and the MLW value is greater than the MLLW value. The number of occurrences of situations where the order is not as it should be is reported.

Initially, many points failed this requirement, so a new version of the filling program, `vpop23.f`, was created (see Section 2.3). Now all points in the new GTX files pass this requirement.

Tidal Station Datums Test - The next test is for compatibility of the GTX files with the official tidal datums at each water level station in the VDatum region. This is accomplished using the program `test_sta9.f`, which reads the latest file of datums (`merged_20120224.dat`) for CO-OPS stations in the U.S. The program will compare the value of the tidal datum obtained by interpolation from the VDatum GTX files with the corresponding value from the observations. If there are significant mismatches between the GTX values and the datums at tide stations, then the GTX files should be regenerated. The results are shown in the tables below.

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Table 2. Summary of errors (cm) at tide stations in the new inner region. Num is number of stations used.

STATISTIC	DATUM						
	MHHW	MHW	DTL	MTL	MLW	MLLW	TSS
Num	100	100	100	100	100	100	81
StD	0.27	0.23	0.08	0.07	0.29	0.30	0.22
Avg	0.02	0.01	0.00	0.00	-0.02	-0.02	0.00
RMS	0.27	0.23	0.08	0.07	0.29	0.30	0.22
Max Abs	1.62	1.31	0.30	0.31	1.93	1.88	1.01
Max@Sta	8722495	8722495	8722859	8722495	8722495	8722495	8720357

Table 3. Summary of errors (cm) at tide stations in the new outer region. Num is number of stations used.

STATISTIC	DATUM						
	MHHW	MHW	DTL	MTL	MLW	MLLW	TSS
Num	12	12	12	12	12	12	12
StD	0.16	0.41	0.08	0.08	0.33	0.22	0.26
Avg	-0.04	-0.13	-0.04	-0.04	0.06	-0.03	0.03
RMSE	0.17	0.43	0.09	0.09	0.33	0.22	0.26
MaxAbs	0.34	1.42	0.24	0.27	0.89	0.69	0.61
Max@Sta	8720692	8722670	8722670	8722670	8722670	8720692	8721120

Continuity Test - This test applies when a new region is adjacent to another VDatum region, or more specifically, when the bounding polygon of the new region has any side in common with the bounding polygon of an existing region. Here the program `test_con10.f` is used to compare transformations across the water regions of interface between the two regions. The results are shown in the table below.

Table 4. Maximum differences (cm) across the interface between pairs of adjacent regions for several datums. There is no adjacent boundary between the Inner region and both the North (South Carolina/Georgia VDatum) and the South (Florida – Florida Bay VDatum).

Region 1	Region 2	DATUM						
		MHHW	MHW	DTL	MTL	MLW	MLLW	TSS
Inner	Outer	0.82	0.90	1.13	1.02	1.15	1.44	0.35
Outer	North	1.39	1.11	0.63	0.51	1.08	1.13	0.02
Outer	South	0.52	0.76	0.05	0.09	0.60	0.61	0.83
North	Central NC	0.39	0.39	0.05	0.06	0.44	0.37	6.98

5. UNCERTAINTY ANALYSIS

As part of the implementation process, the uncertainty must be established to update the discussion on the VDatum website (http://vdatum.noaa.gov/download/publications/Estimation_ of_Vertical_Uncertainties_in_VDatum_8_2012.pdf). The maximum cumulative uncertainty (MCU) is the square root of the sum of the square of the uncertainties from the International Terrestrial Reference Frame, Version xx (ITRFxx) through to a tidal datum, following the tidal transformation with the maximum uncertainty (here LMSL to MHHW or LMSL to MLLW).

At present, it is assumed that some uncertainties are constant throughout the U.S. For example, the uncertainties in the data used to create NAD 83 and NAVD 88 are 2.0 cm and 5.0 cm, respectively, and that the uncertainties in the transformation from ITRFxx to NAD 83 and from NAD 83 to NAVD 88 are 2.0 cm and 5.0 cm, respectively (details are discussed on the VDatum website referenced in the above paragraph). The uncertainties in the TSS transformation, the tidal datum transformations, and the tidal datum values vary for each VDatum region, and are discussed below.

The TSS field is the transformation from NAVD 88 to LMSL, and is constructed by spatially interpolating the values at the tide stations. The uncertainty in the TSS field is assumed to consist of two parts: an interpolation uncertainty and a height uncertainty. The interpolation uncertainty estimates the error due to the use of a limited set of tide stations when creating the interpolation. This uncertainty is calculated by analyzing changes in the interpolated field when one station at a time is removed from the input values (a form of jackknifing, a method of error estimation). The height uncertainty reflects the mismatch between the observed value at the tide station and the value the VDatum software predicts for that location. This uncertainty is calculated from the differences at all station locations.

Since the original ADCIRC model grid (Figure 1.b) was so large, it was decided to use a subset of the grid to perform the jackknifing calculations. The subset grid is shown in Figure 10.

The uncertainty in the tidal datum transformations is estimated by comparing the observed tidal datum to the value that has been generated by analyzing the time series of elevations produced by the ADCIRC model. These analyzed values do not include the correction by adding the interpolated error field, and are thought to be a more realistic representation of the errors. The uncertainty in the observed tidal datum values at the tide stations is estimated by analyzing the record of elevations. An uncertainty value is produced at each tide station, and the errors within the bounding polygon are summed to create the final uncertainty.

The values computed for the uncertainties in the TSS transformation, the tidal datum transformations, and the tidal datum values are shown in Table 5. The plots showing the uncertainties for both regions are shown in Figure 11.
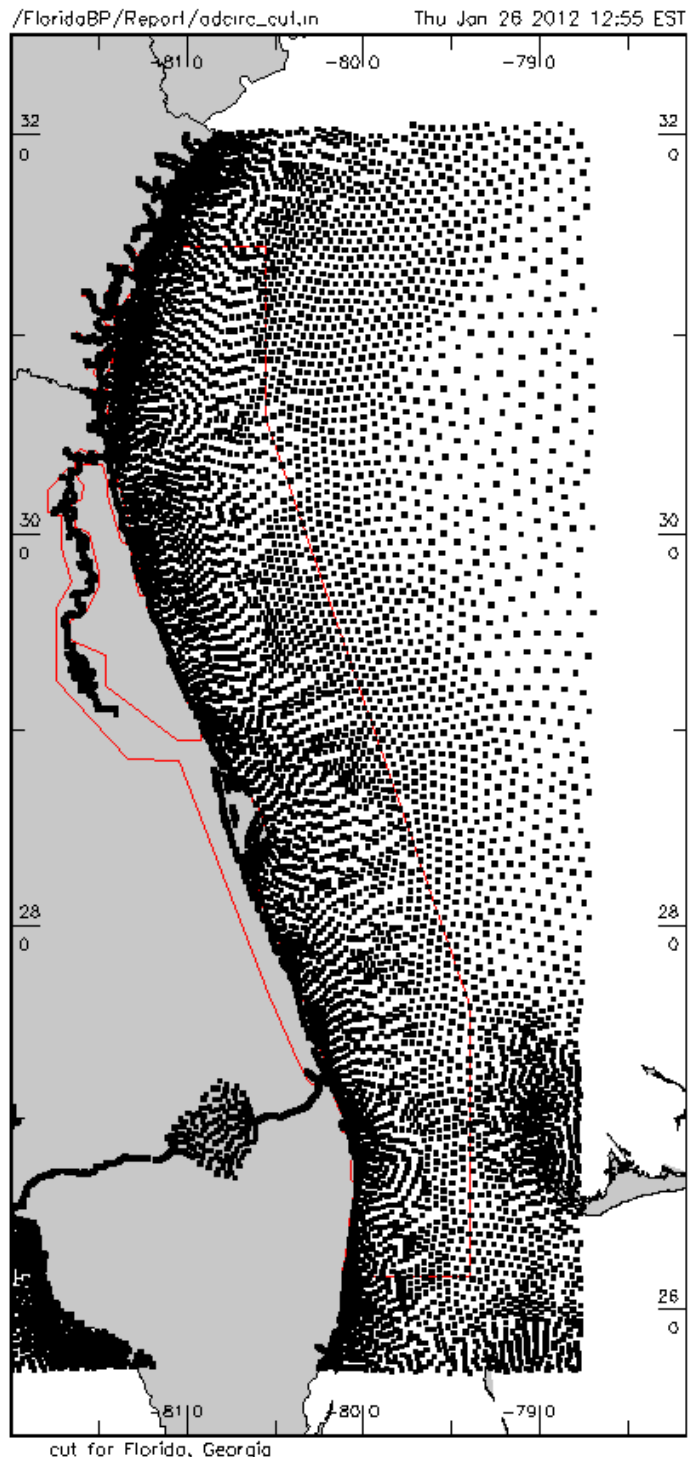
Figure 10. Subset grid used in jackknifing.

Table 5. Portion of Table 3 on the uncertainty website. Uncertainties (one standard deviation, cm) for transformation and source data, and the maximum cumulative uncertainty (MCU).

REGION	TRANSFORMATION							SOURCE DATA	MCU
	NVD88 to MSL	MSL to MHHW	MSL to MHW	MSL to MTL	MSL to DTL	MSL to MLW	MSL to MLLW	All Tidal Datums	
Original VDatum Region									
Florida/Georgia – Fort Lauderdale FL to Sapelo Island	4.3	5.9	5.2	3.3	3.9	4.7	5.1	1.7	10.8
Revised VDatum Regions									
Inner Region: Florida/Georgia – Coastal waterways	3.7	6.5	5.7	3.4	4.0	5.3	5.8	2.1	11.1
Outer Region: Florida/Georgia - Shelf	9.1	5.1	4.3	1.7	1.8	4.3	4.3	1.5	13.1
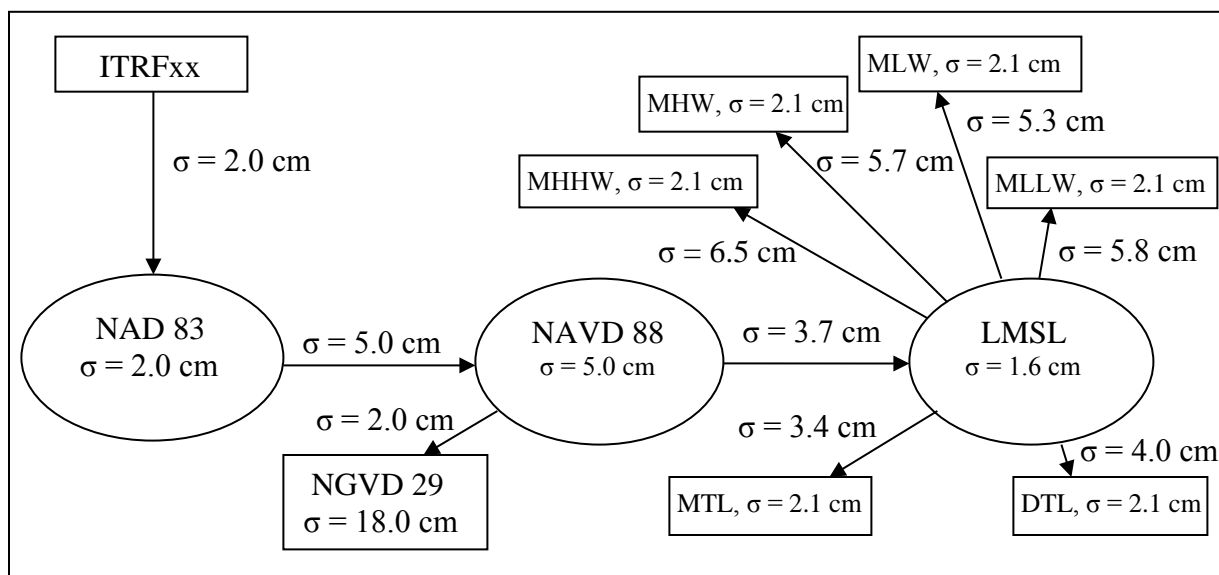
(a)
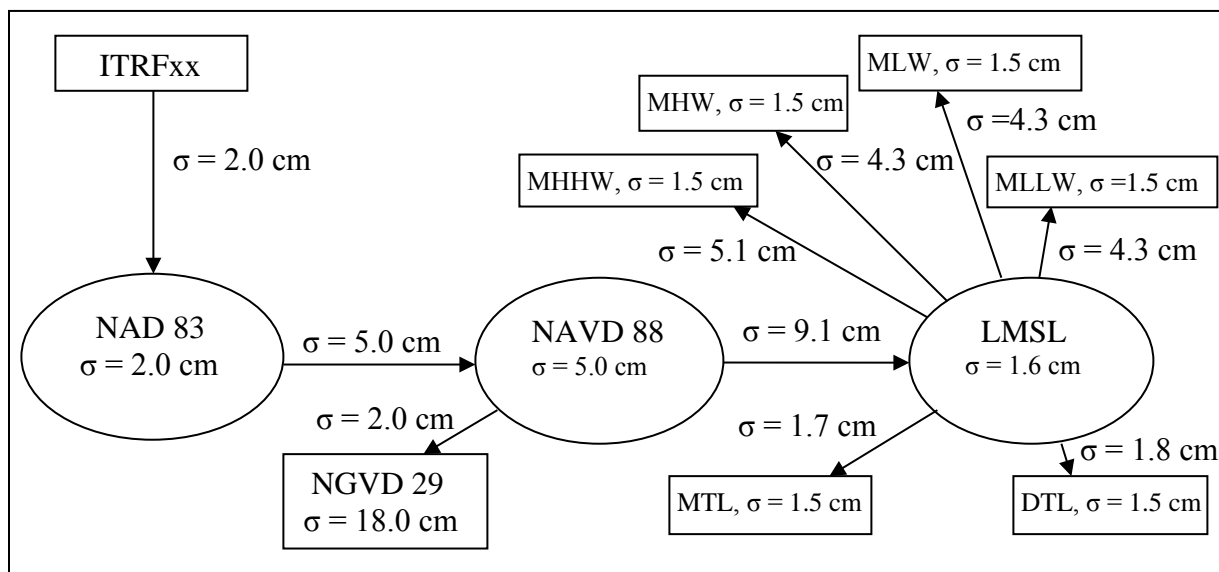
(b)

Figure 11 .The uncertainties in the data and in the transformations, expressed as the standard deviation, or σ, for (a) the inner, or coastal waterways, region and (b) the outer, or shelf, region.

6. SUMMARY

A few years ago, VDatum files were created for a region covering Florida and the South Atlantic Bight, extending along the U.S. coast from the northeast at approximately Wilmington, North Carolina; southward through South Carolina and Georgia; and ending on the western end in the Florida panhandle at Apalachicola Bay. These became operational in April 2010. However, VDatum users at the Jacksonville, Florida, District of the U.S. Army Corps of Engineers (USACE) found some apparent problems in the data when they used VDatum to create gridded fields of the value of the difference between NAVD 88 and MLLW. CSDL reviewed the problems, and found that most occurred in Region D, which we have referred to here as eastern Florida.

The typical problem found by USACE was that the values at locations lying on the land between the inland waterway and the ocean are unrealistic. An examination of the NAVD 88 field and the MLLW field showed that the problem were in the latter field. This is because they were linearly interpolated from the nearest hydrodynamic model values representing, on the landward side, the waterways and, on the seaward side, the coastal ocean. As a result, the values were not truly representative of either body of water. To remedy this problem, Region D was split into two smaller regions, with an inner (western) and outer (eastern) region, each with a new bounding polygon. The border between the two regions would act to separate the inland waterways from the offshore region. This splitting eliminated the problem in overland grid points described by USACE.

Subsequent to the production of the original application for eastern Florida, a new VDatum requirement has been added: designation of non-tidal areas. In these areas, the astronomical tide is small, and as such the difference between Mean Sea Level and any other tidal datum is assumed to be zero. An additional tidal datum, the Low Water Datum, was also introduced. Since there are significant non-tidal areas in Florida, changes in the gridding software were required. In addition, the capability to assess, and modify if necessary, the tidal order was implemented (for correct tidal order, MHHW must be no less than MHW, etc.).

Besides the tidal datums, the topography of the sea surface (TSS) was also regenerated. This surface, as well as the tidal datum fields, relied on the latest data from CO-OPS and NGS. The two new VDatum regions became operational in April 2012.

REFERENCES

Hess, K. W., 2002. Spatial Interpolation of Tidal Data in Irregularly-shaped Coastal Regions by Numerical Solution of Laplace's Equation. **Estuarine, Coastal and Shelf Science**, 54, 175-192.

NOS, 2011: Standard Procedures to Develop and Support NOAA's Vertical Datum Transformation Tool, VDatum. pp 119. NOS, Silver Spring, MD.

Yang, Z., E. P. Myers, I. J. Ieong, and S. A. White, 2012. VDatum for the Coastal Waters from the Florida Shelf to the South Atlantic Bight: Tidal Datums, Marine Grids, and Sea Surface Topography. **NOAA Technical Memorandum** NOS CS 27, pp 97.

APPENDIX A. Summary of Corps of Engineers Comments

Table A. 1. Corps of Engineers Problem Areas in NAVD88-to-MLLW Conversion.

Slide	Area Name	CSDL Region	Perceived Problem	Result of Analysis	NOS Response
15	Port Canaveral, FL	RD	VDatum does not match CO-OPS tide data	no NAVD value when TSS created	Update TSS field
16	Cocoa Beach, FL	RD	VDatum does not match CO-OPS tide data	no NAVD value when TSS created	Update TSS field
17	Port Manatee, FL	RB	VDatum does not match CO-OPS tide data	Erroneous NAVD value at nearby station	Update TSS field
18	St Johns River Entrance, FL	RD	VDatum does not match CO-OPS tide data	no NAVD value when TSS created	Update TSS field
19	Ft. George Inlet and St Johns River Entrance, FL	RD	VDatum values over land do not match either inlet or river	Values interpolated from inlet (ocean) and river values	Update VDatum with new bounding polygon
20	Volusia County, FL	RD	VDatum values over land do not match either ocean or river	Values interpolated from inlet (ocean) and river values	Update VDatum with new bounding polygon
21	Intracoastal Waterway (Gamble Rogers SP)	RD	VDatum values over land do not match either ocean or river	Values interpolated from inlet (ocean) and river values	Update VDatum with new bounding polygon
22	Intracoastal Waterway, Venice, FL	RB	VDatum values not available	COE may have used older data set	Supply COE with new data
23	Manatee River, FL	RB	VDatum values not available	Area not included in VDatum	Extend VDatum coverage
24	Indian River, FL	RD	VDatum does not match CO-OPS tide data	MLLW datum not available	None
25	Banana River, FL	RD	Row of values too low	No problems found	Unknown

APPENDIX B. New Bounding Polygons for Eastern Florida

As discussed in Section 2.1, it was decided to separate the entire region into two along a line (called the dividing line) running from the northern boundary at Sapelo Island, Georgia, to the southern end just north of Fort Lauderdale, Florida. This discussion concerns the decision of where to set the upper and lower limits of the dividing line, and hence the new bounding polygons.

The reason for creating two regions is that there can be a problem when the datum values at VDatum points are determined from values in an oceanic tidal zone in one direction and a riverine tidal zone in another; these zones usually have significantly different tidal datum values. Such points will have unrealistic tidal datum values which are partway between those of each zone. This problem can be avoided if (a) there is at least one null point (vertically, horizontally, and diagonally) between VDatum points representing each zone (and the points are populated with data from only one zone), or (b) a bounding polygon is used to separate the source of the input.

Since some users have begun to request datum values as far as 1 nautical mile from the closest water, the problem is usually avoided when the two zones are separated by land of a width of twice that amount, or 2 nautical miles. If the separation is less than that amount, then the use of a bounding polygon is preferred (See Figure B.1).

In Region D, the southern end of the bounding polygon is at the northern edge of the city of Fort Lauderdale, Florida, where the Intracoastal Waterway is a significant feature and the separation of the inland waterway and the ocean is approximately 0.5 nautical miles. Therefore, a new bounding polygon must include this area. Note that for the two new Florida regions, $dx = dy = 0.0015$ deg. At this spacing, dy is 0.090 nautical miles or 166 m, and at the latitude of Cape Canaveral, dx is 0.079 nautical miles or 146 m.
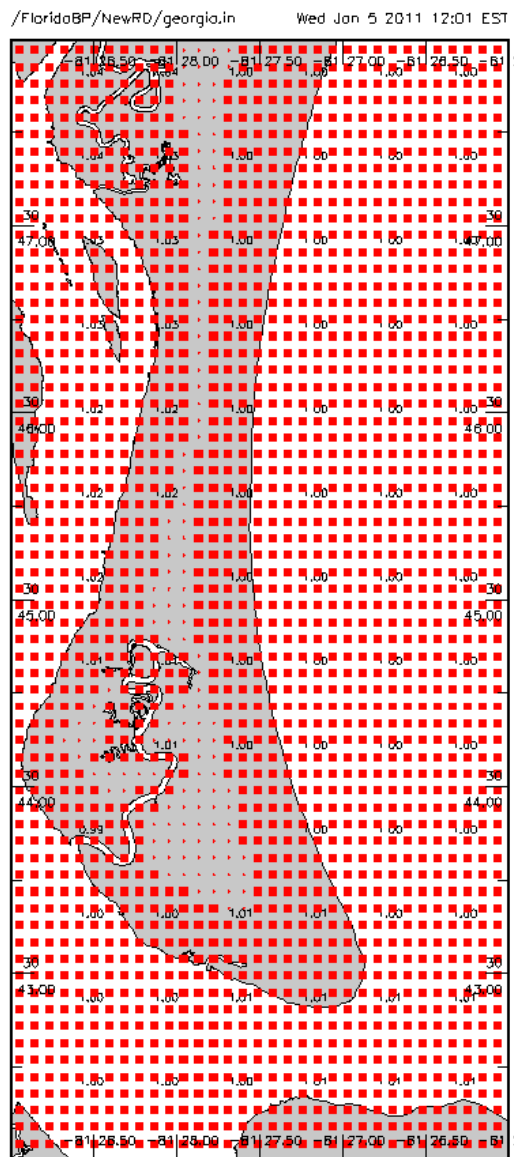
Figure B.1 Southern end of Cumberland Island, Georgia. Red squares = filled VDatum points. The narrowest width is approximately 1.2 nautical miles, and there are not enough intervening nulls in the VDatum points.

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At the northern end (Figure B.2), the presence of an inland river or Intracoastal Waterway continues up to at least the entrance of the St. Johns River, Florida, so the new BP must extend up at least that far. North of the river, the coastal geomorphology changes to a series of relatively wide barrier islands (Amelia Island, Florida, and Cumberland, Jekyll, St. Simons-Sea, Wolf, and Sapelo Island, Georgia) separated from each other by wide river entrances. Since at least the first two islands would require a new BP, it was decided to extend the new BP up to the northern edge of the existing BP at Sapelo Island, Georgia.
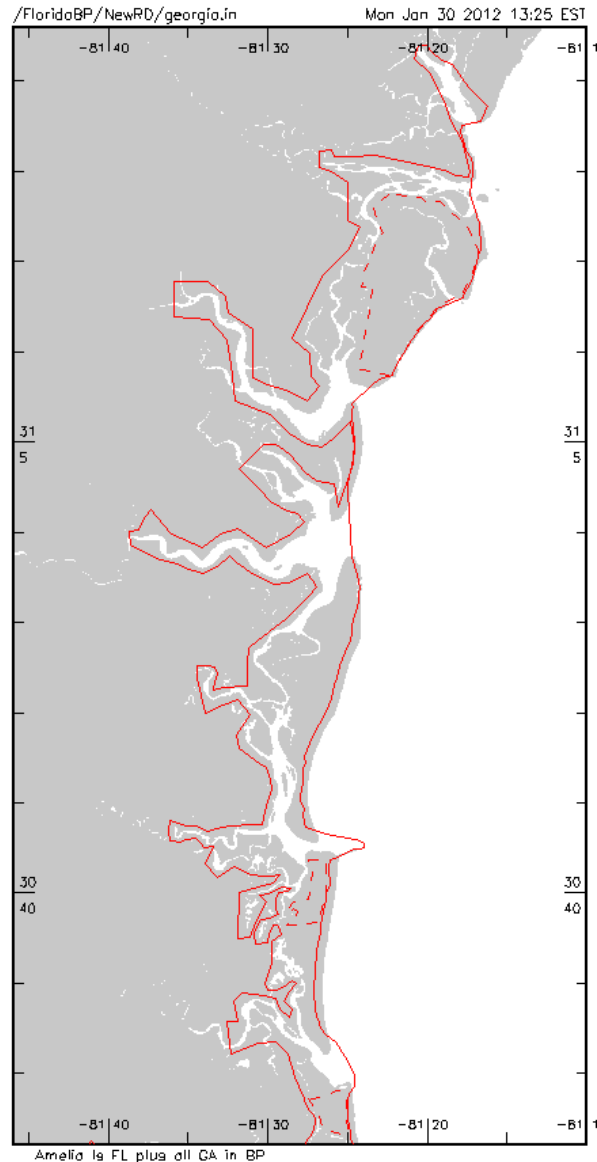
Figure B.2. A portion of coastal southern Georgia and Amelia Island, Florida, showing the revised bounding polygon (red) for the inner region.

APPENDIX C. The Revised Cape Canaveral Non-tidal Polygon

Several adjustments to the original non-tidal polygon (developed by CO-OPS) for the region around Cape Canaveral were made (Figure C.1), primarily to exclude the inlet of Port Canaveral (Figure C.2) from the non-tidal region. The original and the revised polygons are shown below.
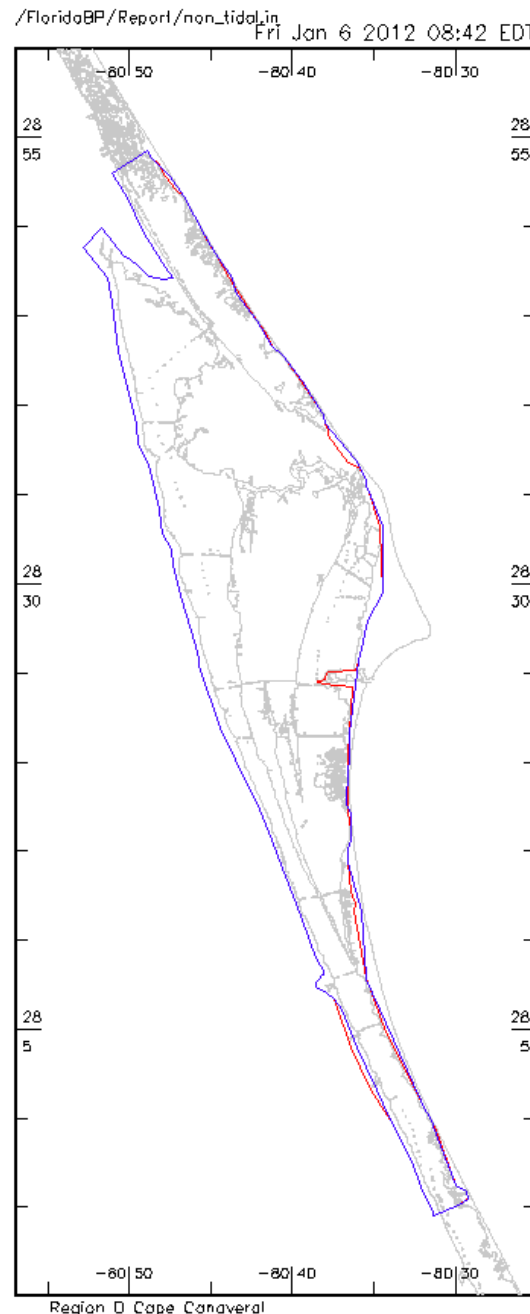
Figure C.1. The original (CO-OPS) non-tidal region boundary (blue) and the revised polygon for new VDatum (red).
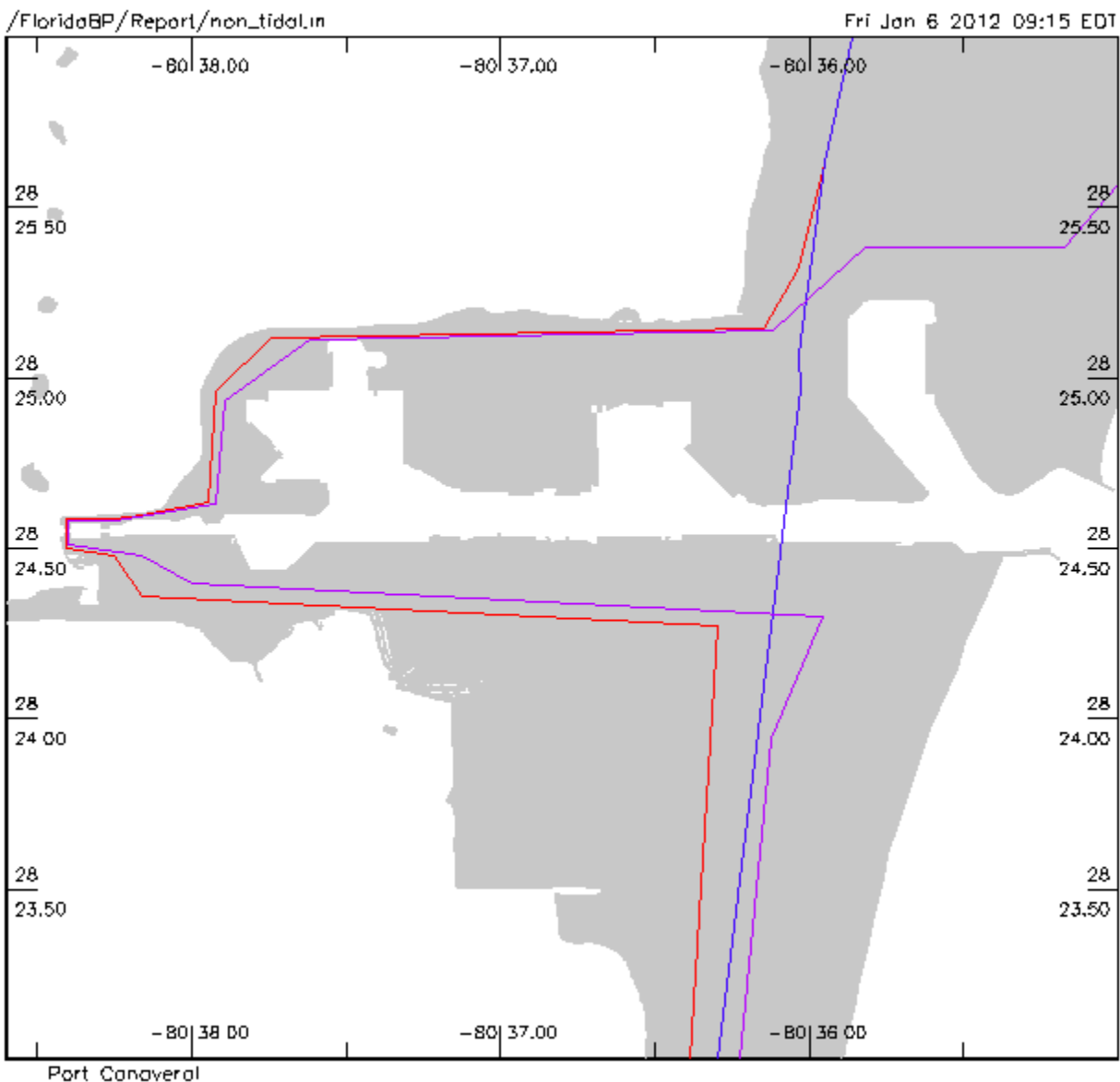
Figure C.2 Port Canaveral, Florida. Blue = original (CO-OPS) non-tidal region boundary, red = revised for new VDatum. Purple = bounding polygon defining inner (westward) region and outer (eastward) region.

APPENDIX D. Station Data for the Tidal Datums

Note: The following nine stations were used in Yang et al. (2012), but not in this study: 872-0855, 872-1374, 872-1415, 872-1456, 872-1533, 872-1611, 872-1749, 872-1808, and 872-2706. Also, stations 872-1164, 872-2208, 872-2213, and 872-2219 were used in this study but were not used in Yang et al. (2012).

Table D. 1. Inner region tidal datum values (elevations in meters, relative to MSL) at the tide stations. The value -9.999 denotes a missing datum.

N	Station ID	Latitude	Longitude	MHHW	MHW	MLW	MLLW	NAVD 88
1	8675622	31.390000	-81.288333	1.146	1.025	-1.054	-1.118	-9.999
2	8676329	31.285000	-81.385000	1.065	0.968	-1.126	-1.199	-9.999
3	8679511	30.796667	-81.515000	1.050	0.939	-1.022	-1.084	-9.999
4	8679758	30.763333	-81.471667	1.023	0.915	-0.984	-1.044	-9.999
5	8679945	30.726667	-81.476667	0.994	0.882	-0.922	-0.978	-9.999
6	8679964	30.720000	-81.548333	0.943	0.841	-0.945	-1.005	-9.999
7	8720011	30.708333	-81.465000	1.005	0.900	-0.916	-0.976	-9.999
8	8720030	30.671667	-81.465000	0.995	0.888	-0.947	-1.004	0.161
9	8720051	30.643333	-81.523333	1.043	0.929	-0.999	-1.059	0.153
10	8720058	30.631667	-81.476667	0.990	0.883	-0.938	-0.995	0.147
11	8720086	30.586667	-81.463333	0.917	0.812	-0.830	-0.881	0.122
12	8720098	30.568333	-81.515000	0.785	0.694	-0.754	-0.811	0.073
13	8720135	30.518333	-81.453333	0.911	0.807	-0.765	-0.823	0.150
14	8720137	30.513333	-81.456667	0.881	0.774	-0.765	-0.822	0.158
15	8720143	30.503333	-81.471667	0.868	0.764	-0.784	-0.828	-9.999
16	8720168	30.465000	-81.431667	0.862	0.757	-0.791	-0.829	0.139
17	8720186	30.440000	-81.438333	0.792	0.701	-0.756	-0.799	0.107
18	8720196	30.416667	-81.453333	0.696	0.622	-0.686	-0.724	-9.999
19	8720198	30.406667	-81.510000	0.609	0.548	-0.547	-0.579	-9.999
20	8720203	30.413333	-81.545000	0.552	0.493	-0.565	-0.593	0.104
21	8720211	30.400000	-81.413333	0.785	0.695	-0.727	-0.774	0.173
22	8720214	30.396667	-81.395000	0.831	0.731	-0.733	-0.782	0.187
23	8720215	30.400000	-81.626667	0.434	0.394	-0.397	-0.420	0.098
24	8720217	30.391667	-81.661667	0.426	0.387	-0.378	-0.403	0.109
25	8720218	30.396667	-81.430000	0.755	0.673	-0.706	-0.753	0.163
26	8720219	30.386667	-81.558333	0.544	0.504	-0.539	-0.576	0.121
27	8720220	30.393333	-81.431667	0.747	0.666	-0.692	-0.736	0.181
28	8720221	30.390000	-81.506667	0.605	0.543	-0.558	-0.588	0.131
29	8720224	30.395000	-81.431667	0.761	0.678	-0.707	-0.752	-9.999
30	8720225	30.383333	-81.636667	0.425	0.385	-0.379	-0.403	0.093
31	8720226	30.320000	-81.658333	0.278	0.263	-0.296	-0.329	-9.999
32	8720232	30.376667	-81.448333	0.640	0.560	-0.610	-0.640	0.123
33	8720242	30.360000	-81.620000	0.410	0.381	-0.385	-0.418	0.085
34	8720267	30.323333	-81.438333	0.585	0.523	-0.626	-0.670	0.131
35	8720274	30.310000	-81.610000	0.346	0.314	-0.303	-0.327	0.043

36	8720296	30.278333	-81.705000	0.209	0.180	-0.153	-0.171	0.019
37	8720305	30.253333	-81.430000	0.572	0.506	-0.746	-0.792	0.064
38	8720333	30.228333	-81.663333	0.161	0.140	-0.125	-0.142	-9.999
39	8720357	30.191667	-81.691667	0.148	0.137	-0.132	-0.163	-0.017
40	8720398	30.133333	-81.386667	0.642	0.566	-0.854	-0.910	0.050
41	8720406	30.120000	-81.758333	0.148	0.127	-0.116	-0.130	-0.013
42	8720409	30.135000	-81.630000	0.136	0.118	-0.104	-0.119	-9.999
43	8720496	29.990000	-81.663333	0.142	0.120	-0.119	-0.131	-0.007
44	8720503	29.978333	-81.628333	0.141	0.126	-0.138	-0.164	0.013
45	8720554	29.916667	-81.300000	0.739	0.637	-0.656	-0.710	0.170
46	8720576	29.891667	-81.310000	0.779	0.676	-0.689	-0.740	0.153
47	8720582	29.866667	-81.306667	0.738	0.637	-0.668	-0.726	0.131
48	8720596	29.858333	-81.553333	0.168	0.145	-0.144	-0.157	-0.014
49	8720623	29.793333	-81.271667	0.770	0.672	-0.710	-0.764	0.111
50	8720625	29.801667	-81.548333	0.192	0.179	-0.170	-0.191	0.016
51	8720651	29.768333	-81.258333	0.686	0.591	-0.647	-0.703	0.111
52	8720653	29.763333	-81.561667	0.192	0.165	-0.155	-0.170	0.019
53	8720686	29.715000	-81.238333	0.659	0.564	-0.611	-0.667	0.140
54	8720757	29.615000	-81.205000	0.251	0.207	-0.240	-0.284	-9.999
55	8720767	29.595000	-81.681667	0.176	0.170	-0.147	-0.170	0.022
56	8720774	29.643333	-81.631667	0.212	0.204	-0.186	-0.212	-9.999
57	8720782	29.571667	-81.606667	0.145	0.125	-0.131	-0.141	-9.999
58	8720832	29.476667	-81.675000	0.081	0.076	-0.053	-0.066	-0.054
59	8720833	29.478333	-81.136667	0.169	0.128	-0.139	-0.160	0.078
60	8720954	29.285000	-81.053333	0.118	0.095	-0.085	-0.110	0.149
61	8721136	29.083333	-80.966667	0.236	0.181	-0.169	-0.195	0.166
62	8721138	29.081667	-80.936667	0.507	0.425	-0.414	-0.458	0.226
63	8721147	29.063333	-80.915000	0.547	0.460	-0.466	-0.509	0.275
64	8721164	29.023333	-80.918333	0.431	0.364	-0.375	-0.418	0.196
65	8721191	28.988333	-80.900000	0.376	0.314	-0.292	-0.310	0.150
66	8721222	28.940000	-80.870000	0.214	0.164	-0.160	-0.167	0.151
67	8721223	28.926667	-80.825000	0.115	0.084	-0.054	-0.055	0.121
68	8721832	28.100000	-80.611667	0.036	0.028	-0.022	-0.042	-9.999
69	8721994	27.873333	-80.496667	0.057	0.041	-0.041	-0.063	0.258
70	8722004	27.860000	-80.448333	0.367	0.309	-0.333	-0.374	0.367
71	8722029	27.811667	-80.463333	0.068	0.046	-0.047	-0.068	0.274
72	8722059	27.755000	-80.425000	0.078	0.060	-0.053	-0.068	0.279
73	8722125	27.631667	-80.371667	0.141	0.116	-0.112	-0.131	0.278
74	8722208	27.471667	-80.325000	0.256	0.216	-0.242	-0.290	0.273
75	8722212	27.470000	-80.288333	0.443	0.377	-0.404	-0.465	0.359
76	8722213	27.468333	-80.300000	0.344	0.291	-0.325	-0.376	0.334
77	8722219	27.456667	-80.323333	0.253	0.209	-0.227	-0.269	0.296
78	8722334	27.243333	-80.313333	0.175	0.143	-0.155	-0.192	0.274
79	8722357	27.200000	-80.258333	0.161	0.128	-0.134	-0.168	0.248

80	8722371	27.175000	-80.188333	0.142	0.116	-0.123	-0.157	0.336
81	8722381	27.155000	-80.171667	0.194	0.162	-0.161	-0.201	0.276
82	8722404	27.113333	-80.145000	0.222	0.187	-0.198	-0.238	0.307
83	8722414	27.093333	-80.136667	0.230	0.192	-0.204	-0.246	0.283
84	8722429	27.065000	-80.123333	0.263	0.226	-0.231	-0.271	0.374
85	8722445	27.036667	-80.106667	0.297	0.254	-0.260	-0.302	0.293
86	8722478	26.975000	-80.113333	0.339	0.291	-0.290	-0.337	0.294
87	8722481	26.970000	-80.126667	0.340	0.295	-0.293	-0.340	0.372
88	8722486	26.960000	-80.105000	0.317	0.265	-0.251	-0.289	0.291
89	8722487	26.951667	-80.101667	0.315	0.269	-0.267	-0.305	0.274
90	8722488	26.951667	-80.103333	0.325	0.276	-0.270	-0.316	-9.999
91	8722491	26.951667	-80.080000	0.345	0.294	-0.299	-0.354	0.289
92	8722492	26.946667	-80.090000	0.353	0.307	-0.292	-0.337	0.344
93	8722495	26.943333	-80.073333	0.415	0.363	-0.365	-0.423	0.357
94	8722557	26.826667	-80.055000	0.482	0.422	-0.434	-0.490	0.314
95	8722588	26.770000	-80.051667	0.470	0.417	-0.426	-0.472	0.320
96	8722607	26.733333	-80.041667	0.466	0.406	-0.414	-0.470	0.335
97	8722621	26.705000	-80.045000	0.456	0.399	-0.384	-0.431	0.304
98	8722654	26.645000	-80.045000	0.439	0.386	-0.365	-0.415	0.354
99	8722669	26.613333	-80.046667	0.489	0.428	-0.411	-0.455	-9.999
100	8722718	26.526667	-80.053333	0.446	0.398	-0.355	-0.403	-9.999
101	8722746	26.473333	-80.061667	0.441	0.395	-0.362	-0.404	0.298
102	8722761	26.446667	-80.065000	0.422	0.383	-0.339	-0.386	0.295
103	8722784	26.403333	-80.070000	0.413	0.376	-0.340	-0.389	0.267
104	8722802	26.370000	-80.070000	0.383	0.345	-0.307	-0.353	0.362
105	8722816	26.343333	-80.076667	0.367	0.328	-0.339	-0.385	-9.999
106	8722859	26.260000	-80.085000	0.409	0.370	-0.362	-0.407	0.275
107	8722861	26.258333	-80.081667	0.423	0.381	-0.378	-0.426	0.289
108	8722862	26.256667	-80.080000	0.425	0.385	-0.382	-0.434	0.309

Table D.2. Outer region tidal datum values (elevations in meters, relative to MSL) at the tide stations. The value -9.999 denotes a missing datum.

N	Station ID	Latitude	Longitude	MHHW	MHW	MLW	MLLW	NAVD 88
1	8677344	31.131667	-81.396667	1.109	0.996	-1.016	-1.077	0.200
2	8720194	30.430000	-81.405000	0.979	0.854	-0.808	-0.865	0.136
3	8720291	30.283333	-81.386667	0.935	0.820	-0.726	-0.776	0.180
4	8720587	29.856667	-81.263333	0.827	0.712	-0.693	-0.742	0.214
5	8720692	29.706667	-81.220000	0.661	0.565	-0.544	-0.594	0.101
6	8721120	29.146667	-80.963333	0.719	0.606	-0.584	-0.631	-0.066
7	8721604	28.415000	-80.591667	0.620	0.513	-0.520	-0.573	0.300
8	8721649	28.368333	-80.600000	0.636	0.528	-0.527	-0.575	0.281
9	8721804	28.138333	-80.578333	0.634	0.507	-0.518	-0.580	0.315
10	8722105	27.670000	-80.360000	0.617	0.516	-0.516	-0.573	0.348
11	8722670	26.611667	-80.033333	0.457	0.414	-0.418	-0.460	0.288
12	8722899	26.188333	-80.093333	0.427	0.390	-0.395	-0.446	0.255

APPENDIX E. Station Data for the TSS Field

Table E.1. Station data used for TSS creation. Delta is the difference between the observed NAVD88-to-LMSL value and the TSS grid value.

N	ID	Latitude (deg)	Longitude (deg)	NAVD 88 to MSL (m)	TSS-Derived Value (m)	Delta (m)
1	8658120	34.22667	-77.95333	-0.010	-0.010	-0.0003
2	8658163	34.21333	-77.78667	0.150	0.150	0.0003
3	8658559	34.03167	-77.89333	0.216	0.215	0.0012
4	8658579	34.02333	-77.94667	0.113	0.113	0.0001
5	8658622	34.00333	-77.95500	0.275	0.268	0.0066
6	8658654	33.99000	-77.95667	0.113	0.119	-0.0062
7	8658741	33.95000	-77.95167	0.142	0.141	0.0007
8	8659084	33.91500	-78.01833	0.141	0.141	0.0000
9	8659182	33.90167	-78.08167	0.170	0.170	0.0004
10	8660098	33.87000	-78.57330	0.103	0.103	0.0005
11	8660147	33.86000	-78.58000	0.098	0.099	-0.0005
12	8660166	33.85500	-78.64830	0.017	0.017	-0.0001
13	8660265	33.83500	-78.63330	0.096	0.096	0.0000
14	8660642	33.76670	-78.81500	-0.198	-0.197	-0.0009
15	8660854	33.71330	-78.92170	-0.235	-0.235	-0.0003
16	8660983	33.68670	-79.00500	-0.186	-0.187	0.0005
17	8661070	33.65500	-78.91830	0.136	0.136	0.0002
18	8661139	33.64670	-79.09500	-0.282	-0.282	0.0002
19	8661419	33.57830	-79.00330	0.107	0.107	0.0000
20	8661582	33.54170	-79.02830	0.122	0.121	0.0013
21	8661989	33.43500	-79.12670	-0.037	-0.033	-0.0042
22	8661991	33.43500	-79.18170	-0.075	-0.078	0.0026
23	8662071	33.41170	-79.13500	-0.062	-0.058	-0.0041
24	8662549	33.25170	-79.26830	0.049	0.048	0.0006
25	8662746	33.23500	-79.20330	0.051	0.051	0.0000
26	8662796	33.19500	-79.27500	0.008	0.009	-0.0008
27	8662931	33.36670	-79.25500	-0.054	-0.051	-0.0031
28	8662953	33.41500	-79.25000	0.000	0.000	0.0000
29	8663618	33.07830	-79.46000	0.094	0.094	0.0005
30	8664022	33.00830	-79.92330	-0.127	-0.128	0.0009
31	8664662	32.91000	-79.95170	0.014	0.012	0.0024
32	8665002	32.84830	-80.05170	0.018	0.019	-0.0006
33	8665101	32.83500	-79.98670	0.070	0.070	0.0005
34	8665167	32.82670	-79.78670	0.089	0.088	0.0012
35	8665192	32.82170	-79.90000	0.053	0.053	0.0003
36	8665387	32.78670	-79.79170	0.103	0.103	0.0002
37	8665424	32.67500	-79.95170	0.097	0.096	0.0015
38	8665475	32.78670	-80.10500	-0.036	-0.036	-0.0001
39	8665494	32.78330	-79.78500	0.146	0.145	0.0015

40	8665530	32.78170	-79.92500	0.067	0.066	0.0006
41	8665552	32.77670	-79.81170	0.120	0.119	0.0012
42	8665567	32.77330	-79.84170	0.110	0.110	0.0003
43	8665589	32.77000	-80.06330	-0.012	-0.011	-0.0007
44	8665637	32.76330	-79.85670	0.094	0.095	-0.0007
45	8665641	32.76330	-80.00170	0.019	0.019	-0.0003
46	8665763	32.74670	-80.16500	-0.020	-0.020	0.0000
47	8666017	32.71500	-80.43670	-0.270	-0.271	0.0006
48	8666101	32.70670	-80.15670	-0.007	-0.007	-0.0003
49	8666217	32.69500	-80.22330	0.012	0.012	0.0001
50	8666367	32.68170	-80.41670	-0.155	-0.155	0.0003
51	8666433	32.66830	-80.29330	0.033	0.032	0.0006
52	8666467	32.67000	-79.91670	0.086	0.086	0.0001
53	8666652	32.66170	-79.94500	0.085	0.085	-0.0001
54	8666699	32.64670	-80.25670	0.046	0.045	0.0010
55	8666799	32.63670	-80.34170	0.005	0.005	0.0000
56	8666918	32.62500	-80.16670	0.054	0.054	0.0001
57	8667062	32.60330	-80.13170	0.059	0.059	0.0000
58	8667075	32.60330	-80.28670	0.041	0.041	0.0001
59	8667178	32.58500	-80.22830	0.071	0.070	0.0006
60	8667425	32.54000	-80.34000	0.035	0.035	0.0000
61	8667630	32.50170	-80.29670	0.096	0.096	0.0001
62	8667676	32.49330	-80.34000	0.098	0.096	0.0021
63	8667679	32.49330	-80.32670	0.081	0.093	-0.0118
64	8667733	32.48330	-80.60000	0.098	0.098	0.0003
65	8667972	32.44670	-80.53330	0.058	0.058	-0.0004
66	8667999	32.43000	-80.67500	0.033	0.033	-0.0001
67	8668146	32.40330	-80.45330	0.094	0.093	0.0007
68	8668223	32.38670	-80.77670	0.035	0.035	0.0003
69	8668482	32.34670	-80.89000	0.022	0.022	0.0000
70	8668498	32.34000	-80.46500	0.089	0.089	0.0000
71	8669133	32.22330	-80.77170	0.074	0.073	0.0006
72	8669167	32.22000	-80.66830	0.083	0.083	0.0004
73	8669801	32.08170	-80.87830	0.105	0.104	0.0012
74	8670870	32.03333	-80.90167	0.071	0.071	0.0003
75	8677344	31.13167	-81.39667	0.200	0.195	0.0053
76	8720030	30.67167	-81.46500	0.161	0.161	0.0002
77	8720051	30.64333	-81.52333	0.153	0.153	0.0002
78	8720086	30.58667	-81.46333	0.122	0.122	-0.0001
79	8720098	30.56833	-81.51500	0.073	0.073	0.0005
80	8720135	30.51833	-81.45333	0.150	0.151	-0.0007
81	8720137	30.51333	-81.45667	0.158	0.156	0.0020
82	8720186	30.44000	-81.43833	0.107	0.107	-0.0002
83	8720194	30.43000	-81.40500	0.136	0.137	-0.0005

84	8720203	30.41333	-81.54500	0.104	0.105	-0.0005
85	8720211	30.40000	-81.41333	0.173	0.173	0.0002
86	8720214	30.39667	-81.39500	0.187	0.185	0.0016
87	8720214	30.39667	-81.39500	0.187	0.185	0.0016
88	8720215	30.40000	-81.62667	0.098	0.098	0.0001
89	8720217	30.39167	-81.66167	0.109	0.109	0.0005
90	8720218	30.39667	-81.43000	0.163	0.162	0.0010
91	8720219	30.38667	-81.55833	0.121	0.120	0.0006
92	8720220	30.39333	-81.43167	0.181	0.178	0.0026
93	8720221	30.39000	-81.50667	0.131	0.131	0.0001
94	8720225	30.38333	-81.63667	0.093	0.093	-0.0002
95	8720232	30.37667	-81.44833	0.123	0.124	-0.0006
96	8720242	30.36000	-81.62000	0.085	0.085	0.0002
97	8720267	30.32333	-81.43833	0.131	0.130	0.0008
98	8720291	30.28333	-81.38667	0.180	0.180	0.0001
99	8720296	30.27833	-81.70500	0.019	0.019	0.0002
100	8720305	30.25333	-81.43000	0.064	0.064	-0.0003
101	8720357	30.19167	-81.69167	-0.007	-0.007	-0.0001
102	8720398	30.13333	-81.38667	0.050	0.050	-0.0002
103	8720406	30.12000	-81.75833	-0.013	-0.013	-0.0001
104	8720496	29.99000	-81.66333	-0.007	-0.007	-0.0002
105	8720503	29.97833	-81.62833	0.013	0.013	0.0003
106	8720554	29.91667	-81.30000	0.170	0.169	0.0007
107	8720576	29.89167	-81.31000	0.153	0.153	0.0002
108	8720582	29.86667	-81.30667	0.135	0.135	-0.0002
109	8720587	29.85667	-81.26333	0.214	0.213	0.0014
110	8720596	29.85833	-81.55333	-0.014	-0.013	-0.0006
111	8720623	29.79333	-81.27167	0.111	0.111	-0.0002
112	8720625	29.80167	-81.54833	0.020	0.020	0.0003
113	8720651	29.76833	-81.25833	0.111	0.112	-0.0005
114	8720653	29.76333	-81.56167	0.019	0.019	0.0002
115	8720686	29.71500	-81.23833	0.140	0.140	0.0002
116	8720692	29.70667	-81.22000	0.103	0.105	-0.0017
117	8720767	29.59500	-81.68167	0.022	0.022	0.0005
118	8720832	29.47667	-81.67500	-0.048	-0.048	-0.0002
119	8720833	29.47833	-81.13667	0.078	0.078	-0.0003
120	8720954	29.28500	-81.05333	0.149	0.149	0.0003
121	8721120	29.14667	-80.96333	-0.066	-0.060	-0.0061
122	8721138	29.08167	-80.93667	0.226	0.225	0.0009
123	8721147	29.06333	-80.91500	0.275	0.269	0.0056
124	8721164	29.02333	-80.91833	0.196	0.196	0.0004
125	8721191	28.98833	-80.90000	0.150	0.151	-0.0006
126	8721222	28.94000	-80.87000	0.151	0.151	-0.0001
127	8721223	28.92667	-80.82500	0.121	0.124	-0.0032
128	8721374	28.73330	-80.75670	0.173	0.173	-0.0004
129	8721415	28.67670	-80.65000	0.214	0.213	0.0007
130	8721456	28.62000	-80.80000	0.214	0.214	0.0002

131	8721533	28.51330	-80.61170	0.210	0.210	0.0000
132	8721604	28.41500	-80.59167	0.300	0.300	0.0004
133	8721649	28.36833	-80.60000	0.281	0.281	-0.0003
134	8721749	28.21170	-80.66330	0.224	0.224	0.0000
135	8721804	28.13833	-80.57833	0.315	0.315	0.0001
136	8721994	27.87333	-80.49667	0.258	0.258	0.0000
137	8722004	27.86000	-80.44833	0.367	0.356	0.0108
138	8722029	27.81167	-80.46333	0.274	0.274	0.0000
139	8722059	27.75500	-80.42500	0.279	0.279	0.0001
140	8722105	27.67000	-80.36000	0.348	0.347	0.0008
141	8722125	27.63167	-80.37167	0.278	0.278	0.0000
142	8722208	27.47167	-80.32500	0.273	0.273	-0.0004
143	8722212	27.47000	-80.28833	0.359	0.359	0.0001
144	8722213	27.46833	-80.30000	0.334	0.332	0.0021
145	8722219	27.45667	-80.32333	0.296	0.296	0.0005
146	8722334	27.24333	-80.31333	0.274	0.274	0.0001
147	8722357	27.20000	-80.25833	0.248	0.249	-0.0010
148	8722371	27.17500	-80.18833	0.336	0.335	0.0012
149	8722381	27.15500	-80.17167	0.276	0.278	-0.0016
150	8722404	27.11333	-80.14500	0.307	0.307	0.0003
151	8722414	27.09333	-80.13667	0.283	0.285	-0.0017
152	8722429	27.06500	-80.12333	0.374	0.371	0.0026
153	8722445	27.03667	-80.10667	0.293	0.296	-0.0033
154	8722478	26.97500	-80.11333	0.294	0.294	0.0000
155	8722481	26.97000	-80.12667	0.372	0.371	0.0007
156	8722486	26.96000	-80.10500	0.291	0.293	-0.0016
157	8722487	26.95167	-80.10167	0.274	0.276	-0.0018
158	8722491	26.95167	-80.08000	0.289	0.296	-0.0070
159	8722492	26.94667	-80.09000	0.344	0.339	0.0052
160	8722495	26.94333	-80.07333	0.357	0.355	0.0025
161	8722557	26.82667	-80.05500	0.314	0.314	0.0001
162	8722588	26.77000	-80.05167	0.320	0.320	0.0002
163	8722607	26.73333	-80.04167	0.335	0.335	0.0005
164	8722621	26.70500	-80.04500	0.304	0.305	-0.0007
165	8722654	26.64500	-80.04500	0.354	0.352	0.0016
166	8722670	26.61167	-80.03333	0.288	0.288	0.0000
167	8722706	26.54830	-80.05330	0.222	0.223	-0.0008
168	8722746	26.47333	-80.06167	0.298	0.296	0.0019
169	8722761	26.44667	-80.06500	0.295	0.294	0.0012
170	8722784	26.40333	-80.07000	0.267	0.269	-0.0023
171	8722802	26.37000	-80.07000	0.362	0.362	0.0000
172	8722859	26.26000	-80.08500	0.275	0.282	-0.0067
173	8722861	26.25833	-80.08167	0.289	0.295	-0.0057
174	8722862	26.25667	-80.08000	0.309	0.307	0.0024
175	8722899	26.18833	-80.09333	0.255	0.256	-0.0006

Table E.2. Mean and stand deviations of difference values (meters) for Florida/Georgia TSS Grid subset by region.

	Mean Value (m)	Standard Deviation (m)
Region 1 (FL/GA Embayments)	0.0003	0.0016
Region 2 (FL/GA Outer Coast)	-0.0006	0.0035
Region 3 (GA/SC/NC Region)	0.000003	0.0020